Texas Enviornomental Resource Stewards (TERS): Texas Ecological Assessment Protocol (TEAP) Results Pilot Project

Prepared by

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The Texas Environmental Resource Stewards (TERS) was formed by the Executive Leaders of various federal and state agencies to collaborate on common ecosystem management and regulatory streamlining issues. The Texas Ecological Assessment Protocol (TEAP) is a product of the TERS effort which analyzes existing broad-scale electronic data to identify important ecological areas in Texas that should be avoided or protected, if possible. This report communicates the initial results of this new tool. Agencies and the public will be able to use this information to aid in project planning and scientific research, ultimately leading to better environmental assessments, improved understanding, and enhanced decision-making. The TEAP is not designed to be used to make final decisions on individual projects, but rather to serve as a general screening tool to allow environmental professionals to focus limited resources to protect critical ecological areas and to give the public an overview of environmental conditions in Texas.

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Table of Contents

Chapter Page

EXECUTIVE SUMMARY 1
Background 1
Diversity 2
Rarity 2
Sustainability 3
Actions 4

1.0 INTRODUCTION 9
1.1 TERS History 9
1.2 Texas Ecological Assessment Protocol (TEAP) Goals 11
1.3 Background 12
1.3.1 Geographical Information System (GIS)-Based Assessments 12
1.3.2 Ecoregion Delineation 14
1.3.2.1 Types of Ecoregion Delineation 15
1.3.3 Ecological Theory Used in TEAP 15
1.3.3.1 Diversity 20
1.3.3.1.1 Appropriateness of Land Cover 20
1.3.3.1.2 Contiguous Size of Undeveloped Land 20
1.3.3.1.3 Shannon Land Cover Diversity Index 21
1.3.3.1.4 Ecologically Significant Stream Segments 22
1.3.3.2 Rarity 23
1.3.3.2.1 Vegetation Rarity 24
1.3.3.2.2 Natural Heritage Rank 24
1.3.3.2.3 Taxonomic Richness 25
1.3.3.2.4 Rare Species Richness 25
1.3.3.3 Sustainability 26
1.3.3.3.1 Contiguous Land Cover Type 26
1.3.3.3.2 Regularity of Ecosystem Boundary 27
1.3.3.3.3 Appropriateness of Land Cover 30
1.3.3.3.4 Waterway Obstruction 30
1.3.3.3.5 Road Density 30
1.3.3.3.6 Airport Noise 31
1.3.3.3.7 Superfund National Priority List (NPL) and State Superfund Sites 31
1.3.3.3.8 Water Quality 32
1.3.3.3.9 Air Quality 32
1.3.3.3.10 RCRA, TSD, Corrective Action and State VCP Sites 33
1.3.3.3.11 Urban/Agriculture Disturbance 34
1.3.4 TEAP Development 34
1.3.4.1 TPWD Conservation Planning 35

1.3.4.2 The Nature Conservancy Ecoregional Planning Process 35
1.3.4.3 EPA Region 5 CrEAM 37

2. 0 METHODS 44
2.1 Base Unit Selection 44
2.2 TEAP Sub-layers and Layers 47
2.2.1 Diversity Layer 47
2.2.1.1 Appropriateness of Land Cover 47
2.2.1.2 Contiguous Size of Undeveloped Land 57
2.2.1.3 Shannon Land Cover Diversity Index 57
2.2.1.4 Ecologically Significant Stream Segments 58
2.2.2 Rarity Layer 59
2.2.2.1 Vegetation Rarity 59
2.2.2.2 Natural Heritage Rank 60
2.2.2.3 Taxonomic Richness 62
2.2.2.4 Rare Species Richness 63
2.2.3 Sustainability Layer 63
2.2.3.1 Contiguous Land Cover Type 63
2.2.3.2 Regularity of Ecosystem Boundary 64
2.2.3.3 Appropriateness of Land Cover 65
2.2.3.4 Waterway Obstruction 66
2.2.3.5 Road Density 66
2.2.3.6 Airport Noise 68
2.2.3.7 Superfund NPL and State Superfund Sites 69
2.2.3.8 Water Quality 69
2.2.3.9 Air Quality 69
2.2.3.10 RCRA, TSD, Corrective Action and State VCP Sites 70
2.2.3.11 Urban/Agriculture Disturbance 70
2.2.4 Accuracy Assessment 71

3.0 RESULTS 74
3.1 Diversity Layer 74
3.2 Rarity Layer 74
3.3 Sustainability Layer 77
3.4 Composite Layer 77
3.4.1 Ecoregion Composites 80
3.4.1.1 Southern High Plains 80
3.4.1.2 Texas High Plains 80
3.4.1.3 Rolling Plains 83
3.4.1.4 Rio Grande Plain 83
3.4.1.5 Redbed Plains 83
3.4.1.6 Cross Timbers and Prairie 83
3.4.1.7 Oak Woods and Prairies 88
3.4.1.8 Blackland Prairie 88
3.4.1.9 Mid Coastal Plains, Western Section 88
3.4.1.10 Coastal Plains and Flatwoods, Western Gulf Section 88

3.4.1.11 Edwards Plateau 92
3.4.1.12 Stockton Plateau 92
3.4.1.13 Chihuahuan Desert Basin and Range 92
3.4.1.14 Sacramento-Manzano Mountain 97
3.4.1.15 Louisiana Coast Prairies and Marshes 97
3.4.1.16 Eastern Gulf Prairies and Marshes 97
3.4.1.17 Central Gulf Prairies and Marshes 97
3.4.1.18 Southern Gulf Prairies and Marshes 102
3.4.2 Overlays 102
3.4.3 Accuracy Assessment 102

4.0 DISCUSSION 112
4.1 Data Limitations 113
4.2 Accuracy Assessment 117
4.3 Conservation 118

5.0 CONCLUSIONS 120
5.1 Streamlining 120
5.2 Next Steps 120

6.0 ACKNOWLEDGMENTS 122

7.0 REFERENCES 123

APPENDIX A: Descriptions of Bailey's Ecoregions 134
Southeastern Mixed Forest 140
Mid Coastal Plains, Western (Section 231E) 140
Geomorphology 140
Lithology and Stratigraphy 140
Soil Taxa 140
Potential Natural Vegetation 141
Fauna 141
Climate 141
Surface Water Characteristics 141
Disturbance Regimes 141
Land Use 141
Eastern Gulf Prairies and Marshes (Section 231F) 141
Geomorphology 141
Lithology and Stratigraphy 142
Soil Taxa 142
Potential Natural Vegetation 142
Fauna 143
Climate 143
Surface Water Characteristics 143
Disturbance Regimes 143
Land Use 143

Outer Coastal Plain Mixed Forest 143
Louisiana Coast Prairies and Marshes (Section 232E) 143
Geomorphology 143
Lithology and Stratigraphy 144
Soil Taxa 144
Potential Natural Vegetation 144
Fauna 144
Climate 145
Surface Water Characteristics 145
Disturbance Regimes 145
Land Use 145
Coastal Plains and Flatwoods, Western Gulf (Section 232F) 145
Geomorphology 145
Lithology and Stratigraphy 146
Soil Taxa 146
Potential Natural Vegetation 146
Fauna 146
Climate 146
Surface Water Characteristics 147
Disturbance Regimes 147
Land Use 147

Prairie Parkland (Subtropical) 147
Cross Timbers and Prairies (Section 255A) 147
Geomorphology 147
Lithology and Stratigraphy 148
Soil Taxa 148
Potential Natural Vegetation 148
Fauna 148
Climate 148
Surface Water Characteristics 148
Disturbance Regimes 149
Land Use 149
Blackland Prairies (Section 255B) 149
Geomorphology 149
Lithology and Stratigraphy 149
Soil Taxa 149
Potential Natural Vegetation 150
Fauna 150
Climate 150
Disturbance Regimes 150
Land Use 150
Oak Woods and Prairies (Section 255C) 150
Geomorphology 150
Lithology and Stratigraphy 151

Soil Taxa 151
Potential Natural Vegetation 151
Fauna 151
Climate 152
Surface Water Characteristics 152
Disturbance Regimes 152
Land Use 152
Central Gulf Prairies and Marshes (Section 255D) 152
Geomorphology 152
Lithology and Stratigraphy 153
Soil Taxa 153
Potential Natural Vegetation 153
Fauna 153
Climate 153
Surface Water Characteristics 153
Disturbance Regimes 154
Land Use 154

Great Plains Steppe and Shrub 154
Redbed Plains (Section 311A) 154
Geomorphology 154
Lithology and Stratigraphy 155
Soil Taxa 155
Potential Natural Vegetation 155
Fauna 155
Climate 155
Surface Water Characteristics 155
Disturbance Regimes 155
Land Use 155

Southwest Plateau and Plains Dry Steppe and Shrub 156
Texas High Plains (Section 315B) 156
Geomorphology 156
Lithology and Stratigraphy 156
Soil Taxa 156
Potential Natural Vegetation 156
Fauna 156
Climate 157
Surface Water Characteristics 157
Disturbance Regimes 157
Land Use 157
Rolling Plains (Section 315C) 158
Geomorphology 158
Lithology and Stratigraphy 158
Soil Taxa 158
Potential Natural Vegetation 159

Fauna 159
Climate 159
Surface Water Characteristics 159
Disturbance Regimes 159
Land Use 159
Edwards Plateau (Section 315D) 159
Geomorphology 159
Lithology and Stratigraphy 160
Soil Taxa 160
Potential Natural Vegetation 160
Fauna 160
Climate 161
Surface Water Characteristics 161
Disturbance Regimes 161
Land Use 161
Rio Grande Plain (Section 315E) 161
Geomorphology 161
Lithology and Stratigraphy 161
Soil Taxa 161
Potential Natural Vegetation 162
Fauna 162
Climate 163
Surface Water Characteristics 163
Disturbance Regimes 163
Land Use 163
Southern Gulf Prairies and Marshes (Section 315F) 163
Geomorphology 163
Lithology and Stratigraphy 164
Soil Taxa 164
Potential Natural Vegetation 164
Fauna 164
Climate 164
Surface Water Characteristics 164
Disturbance Regimes 165
Land Use 165

Arizona-New Mexico Mountains Semi-Desert - Open Woodland - Coniferous Forest - Alpine Meadow 165
Sacramento-Manzano Mountain (Section M313B) 165
Geomorphology 165
Lithology and Stratigraphy 165
Soil Taxa 166
Potential Natural Vegetation 166
Climate 166
Surface Water Characteristics 166
Disturbance Regimes 166

Cultural Ecology 166

Chihuahuan Semi-Desert 167
Basin and Range (Section 321A) 167
Geomorphology 167
Lithology and Stratigraphy 168
Soil Taxa 168
Potential Natural Vegetation 168
Climate 168
Surface Water Characteristics 168
Disturbance Regimes 169
Land Use 169
Cultural Ecology 169
Stockton Plateau (Section 321B) 169
Geomorphology 169
Lithology and Stratigraphy 170
Soil Taxa 170
Potential Natural Vegetation 170
Fauna 170
Climate 171
Surface Water Characteristics 171
Disturbance Regimes 171
Land Use 171

Great Plains-Palouse Dry Steppe 171
Southern High Plains (Section 331B) 171
Geomorphology 171
Lithology and Stratigraphy 172
Soil Taxa 172
Potential Natural Vegetation 172
Fauna 172
Climate 172
Surface Water Characteristics 172
Land Use 172

APPENDIX B: Individual sub-layer maps 173
Diversity layer 176
Rarity layer 177
Sustainability layer 179
Figures 181

APPENDIX C: List of Acronyms 200

APPENDIX D: List of contributors 205

List of Tables

Table 1. TPWD planning results. Priority ecoregions for conservation efforts 36

Table 2. Relationship of the EPA SAB framework ecological attributes to EPA Region 5 CrEAM and TEAP 39

Table 3. Summary of TEAP layers. 48

Table 4. GIS data layers used for TEAP. 53

Table 5. Kuchler (1964) PNV classifications and corresponding NLCD land cover types 55

List of Figures

Figure A. Map of the diversity layer with ecoregion boundaries.. 5

Figure B. Map of the rarity layer with ecoregion boundaries. 6

Figure C. Map of the sustainability layer with ecoregion boundaries.. 7

Figure D. Composite map with ecoregion boundaries.. 8

Figure 1. Map of Bailey's ecoregion sections. 16

Figure 2. Map of Omernik ecoregions. 17

Figure 3. Map of Gould's vegetation types. 18

Figure 4. Map of Texas natural areas 19

Figure 5. Map of the diversity layer with ecoregion boundaries. This map is a composite of four sub-layers (Figures B1-B4) 75

Figure 6. Map of the rarity layer with ecoregion boundaries. This map is a composite of four sub-layers (Figures B5-B8) 76

Figure 7. Map of the sustainability layer with ecoregion boundaries. This map is a composite of eleven sub-layers (Figures B9-B19).. 78

Figure 8. Composite map with ecoregion boundaries. This map is a composite of the diversity layer (Figure 5), rarity layer (Figure 6), and

sustainability layer (Figure 7).. 79

Figure 9. Southern High Plains composite map. A separate figure (Figure 8) shows the entire state.. 81

Figure 10. Texas High Plains composite map. A separate figure (Figure 8) shows the entire state.. 82

Figure 11. Rolling Plains composite map. A separate figure (Figure 8) shows the entire state 84

Figure 12. Rio Grande Plain composite map. A separate figure (Figure 8) shows the entire state 85

Figure 13. Redbed Plains composite map. A separate figure (Figure 8) shows the entire state 86

Figure 14. Cross Timbers and Prairie composite map. A separate figure (Figure 8) shows the entire state 87

Figure 15. Oak Woods and Prairies composite map. A separate figure (Figure 8) shows the entire state 89

Figure 16. Blackland Prairie composite map. A separate figure (Figure 8) shows the entire state 90

Figure 17. Mid Coastal Plains Western Section composite map. A separate figure (Figure 8) shows the entire state 91

Figure 18. Coastal Plains and Flatwoods Western Gulf Section composite map. A separate figure (Figure 8) shows the entire state. 93

Figure 19. Edwards Plateau composite map. A separate figure (Figure 8) shows the entire state 94

Figure 20. Stockton Plateau composite map. A separate figure (Figure 8) shows the entire state 95

Figure 21. Chihuahuan Desert Basin and Range composite map. A separate figure (Figure 8) shows the entire state 96

Figure 22. Sacramento-Manzano Mountain composite map. A separate figure (Figure 8) shows the entire state 98

Figure 23. Louisiana Coast Prairies and Marshes composite map. A separate figure (Figure 8) shows the entire state 99

Figure 24. Eastern Gulf Prairies and Marshes composite map. A separate figure (Figure 8) shows the entire state 100

Figure 25. Central Gulf Prairies and Marshes composite map. A separate figure (Figure 8) shows the entire state 101

Figure 26. Southern Gulf Prairies and Marshes composite map. A separate figure (Figure 8) shows the entire state 103

Figure 27. Composite map with public lands overlay. Public lands include National and State Parks, National Forests and Grasslands, Department of Defense lands, and National Wildlife Refuges. 104

Figure 28. Composite map with transportation corridors overlay. IH69 and Trans Texas Corridor are included 105

Figure 29. Composite map with watershed boundary overlay 106

Figure 30. Map depicting areas used for the accuracy assessment. 107

Figure 31. a) Statewide frequencies of TEAP composite scores (by class) that occur inside and outside TNC portfolio; b) statewide frequencies expressed as a percentage of TEAP composite scores occurring inside and outside TNC portfolio. 108

Figure 32. Map of proposed IH69 corridor depicting areas used for the accuracy assessment. 110

Figure 33. a) IH69 corridor frequencies of TEAP composite scores (by class) that occur inside and outside TNC portfolio; b) IH69 corridor frequencies expressed as a percentage of TEAP composite scores occurring inside and outside TNC portfolio 111

Figure B1. Map of diversity sub-layer: appropriateness of land cover. This map is used to produce the map of the diversity layer (Figure 5). 181

Figure B2. Map of diversity sub-layer: contiguous size of undeveloped land. This map is used to produce the map of the diversity layer (Figure 5). 182

Figure B3. Map of diversity sub-layer: Shannon land cover diversity index. This map is used to produce the map of the diversity layer (Figure 5). 183

Figure B4. Map of diversity sub-layer: ecologically significant stream segments. This map is used to produce the map of the diversity layer (Figure 5). 184

Figure B5. Map of rarity sub-layer: vegetation rarity. This map is used to produce the map of the rarity layer (Figure 6). 185

Figure B6. Map of rarity sub-layer: natural heritage rank. This map is used to produce the map of the rarity layer (Figure 6). 186

Figure B7. Map of rarity sub-layer: taxonomic richness. This map is used to produce the map of the rarity layer (Figure 6). 187

Figure B8. Map of rarity sub-layer: rare species richness. This map is used to produce the map of the rarity layer (Figure 6). 188

Figure B9. Map of sustainability sub-layer: contiguous land cover type. This map is used to produce the map of the sustainability layer (Figure 6). 189

Figure B10. Map of sustainability sub-layer: regularity of ecosystem boundary. This map is used to produce the map of the sustainability layer (Figure 7). 190

Figure B11. Map of sustainability sub-layer: appropriateness of land cover. This map is used to produce the map of the sustainability layer (Figure 7). 191

Figure B12. Map of sustainability sub-layer: waterway obstruction. This map is used to produce the map of the sustainability layer (Figure 7). 192

Figure B13. Map of sustainability sub-layer: road density. This map is used to produce the map of the sustainability layer (Figure 7). 193

Figure B14. Map of sustainability sub-layer: airport noise. This map is used to produce the map of the sustainability layer (Figure 7). 194

Figure B15. Map of sustainability sub-layer: Superfund National Priority List and state Superfund Sites. This map is used to produce the map of the sustainability layer (Figure 7). 195

Figure B16. Map of sustainability sub-layer: water quality. This map is used to produce the map of the sustainability layer (Figure 7). 196

Figure B17. Map of sustainability sub-layer: air quality. This map is used to produce the map of the sustainability layer (Figure 7). 197

Figure B18. Map of sustainability sub-layer: RCRA TSD, corrective action and state VCP sites. This map is used to produce the map of the sustainability layer (Figure 7). 198

Figure B19. Map of sustainability sub-layer: urban/agriculture disturbance. This map is used to produce the map of the sustainability layer (Figure 7). 199

EXECUTIVE SUMMARY

Background

Texas Environmental Resource Stewards (TERS) was established in July 2002 to seek greater federal and state interagency collaboration on identifying and supporting joint priorities, particularly regarding transportation issues. Leaders from participating agencies identified common interests and target activities for collaborative ecosystem management of benefit to each agency. Common interests included identification of ecologically important natural resource areas (wetland, aquatic, and terrestrial) for avoidance, or potential compensatory mitigation, preservation, or restoration; "streamlining" of regulatory processes; early identification of some National Environmental Policy Act (NEPA) requirements in project planning; and analysis of cumulative impacts. The TERS executives developed a vision which included the following actions:

Improve mutual understanding

Use collective knowledge to support decision-making

Strive for synergism

The initial approach to achieving a portion of the TERS vision was to develop an ecosystem approach to organize strategies that achieve effective and measurable environmental results, and jointly communicate the results to the public. The initial goals of TERS were to identify ecologically important areas, identify potential mitigation areas, and streamline regulatory processes. This report serves to communicate progress on the first goal: the ecological assessment and identification of ecologically important resources in the state of Texas.

Technical experts from participating TERS agencies agreed to (1) develop a scientifically valid, ecosystem prioritization protocol for Texas; (2) apply this protocol to existing, available data using GIS; and (3) demonstrate the protocol to identify areas of highest ecological importance in Texas. The Texas Ecological Assessment Protocol (TEAP) relies on a previously developed methodology and consists of collecting and analyzing existing electronic data available statewide, which was used to evaluate the following three ecological criteria:

1.	Diversity	What areas have the most diverse land cover?
2.	Rarity	What areas have the highest number of rare species and land cover types?
3.	Sustainability	What areas can sustain ecosystems now and in the future?

Chapter 2 of the full report provides details of TEAP. The results of the analysis for each layer within each ecoregion are summarized below (Figures A-C). The eighteen ecoregion sections developed by Bailey (1994) were used.

Diversity (Figure A): The diversity map shows higher diversity in west Texas (Chihuahuan Desert Basin and Range ecoregion). There are areas of high diversity in the southern portion of the Rolling Plains ecoregion, and the Rio Grande Plain ecoregion.

Rarity (Figure B): The rarity map shows the areas of highest rarity are in the Stockton Plateau and the Coastal Plains and Flatwoods Western Gulf Section ecoregions. In addition, areas in the Chihuahuan Desert Basin and Range, Edward's Plateau, Oak Woods and Prairies, and the southern portion of the Rio Grande Plain ecoregion show moderately high levels of rarity.

Sustainability (Figure C): Figure C shows the combination of all eleven layers in a map representing sustainability. There are only a few highly sustainable (top 1%, 10%) locations in the Chihuahuan Desert Basin and Range, Stockton Plateau, southern Rio Grande Plain, southern Rolling Plains, and a few other areas in Texas. The more sustainable areas occur where there are fewer human disturbance activities. Most of the population lives in the eastern half of the state. Thus, the Cross Timbers and Prairies, Central Gulf Prairies and Marshes, Mid Coastal Plains Western Section, and Blackland Prairies ecoregions show the lowest sustainability.

These three layers were combined into a composite map that shows where ecologically important areas occur in Texas (Figure D). The top 1% highly ecologically important areas in Texas are highlighted in red. Most of the ecologically important (1%, 10%) areas are located in Chihuahuan Desert Basin and Range, Stockton Plateau, and Rio Grande Plain ecoregions. Other areas that have high or moderately high ecologically important areas are the Edwards Plateau and the southern portion of the Mid Coastal Plains Western Section. Conversely, the most threatened areas are in the Blackland Prairies, Oak Woods and Prairies, Central Gulf Prairies and Marshes, and Louisiana/Eastern Gulf Prairies and Marshes ecoregions which TEAP indicates have the least sustainable ecological areas. The Nature Conservancy (The Conservancy) performed an independent accuracy assessment on the TEAP comparing the composite scores and The Conservancy portfolio sites. This assessment showed, in general, that those areas ranked as highly important ecologically by TEAP corresponded to areas identified as very ecologically important in The Conservancy portfolio. Field investigation would be necessary to better determine the accuracy of locations that had low TEAP composite scores.

TEAP was applied to rapidly assess the entire Texas landscape by ecoregion through the use of a statewide GIS grid. The results of TEAP provide a tool for use in project planning and for reducing very large corridors to more manageable areas for more detailed field investigation. Identification of ecologically important areas in each ecoregion can be used as a tool to support ecosystem-driven mitigation sequencing (avoidance of impacts, minimization, and then compensation) and conservation planning throughout the state. TEAP can also be used to find high quality habitat remnants in all ecoregions in Texas. The TEAP is intended to be a supplemental tool for agency use, not to circumvent or replace agency policies, processes, or regulations.

Actions

Updated analyses using 2002 land cover data can be performed once this data is made available in a GIS format. In addition, several other databases (e.g., pipelines, oil and gas wells) were suggested for incorporation. These databases, as well as modifications to the current protocol, can be made in subsequent iterations. TEAP will be reevaluated every 2 to 3 years when new land cover and other data become available. Therefore, TEAP can be used to identify trends in ecological condition by comparing results from previous years.

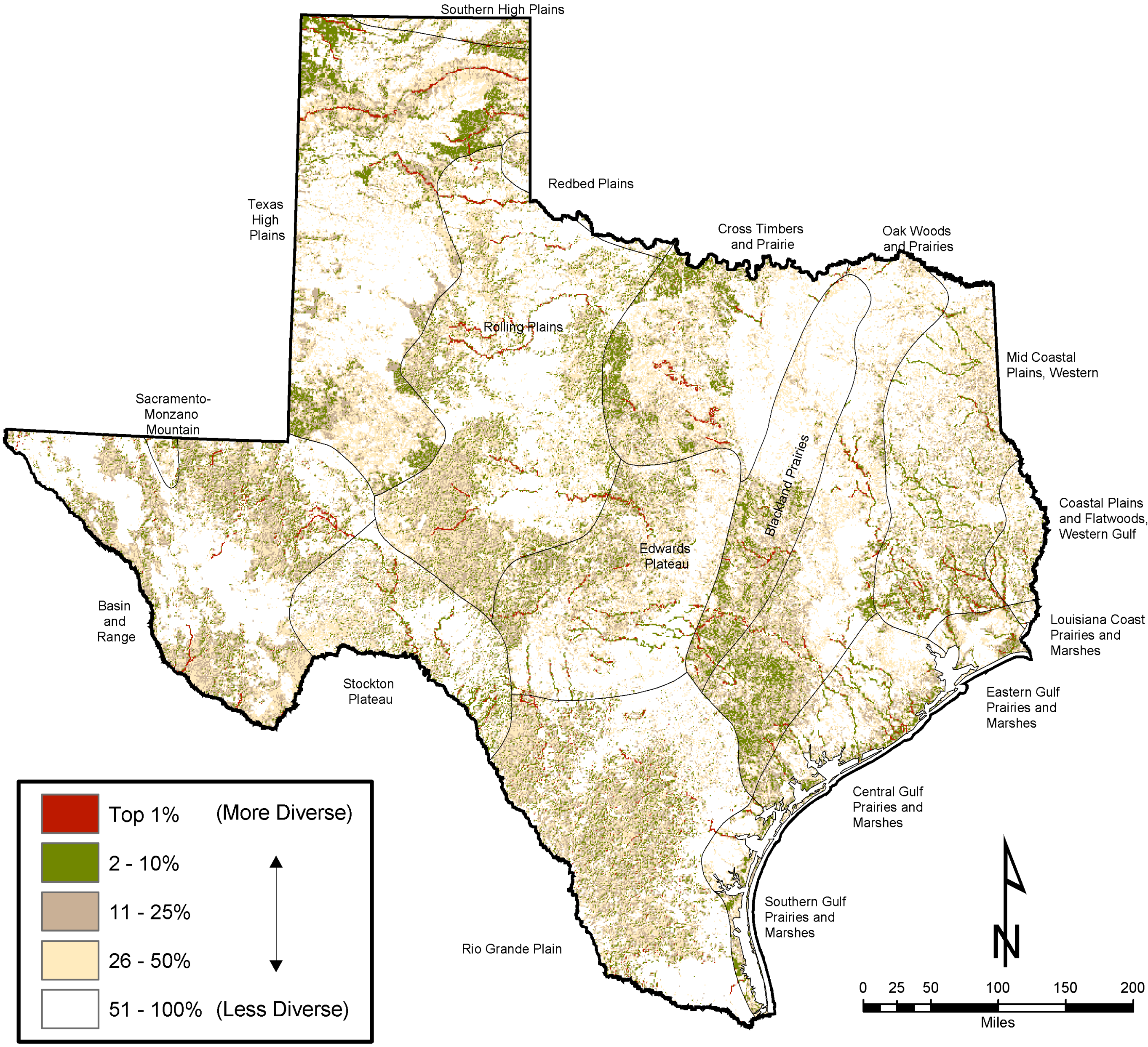

Figure A. Map of the diversity layer with ecoregion boundaries. This map is a composite of four sub-layers: appropriateness of land cover, contiguous size of undeveloped land, Shannon land cover diversity index, and ecologically significant stream segments.

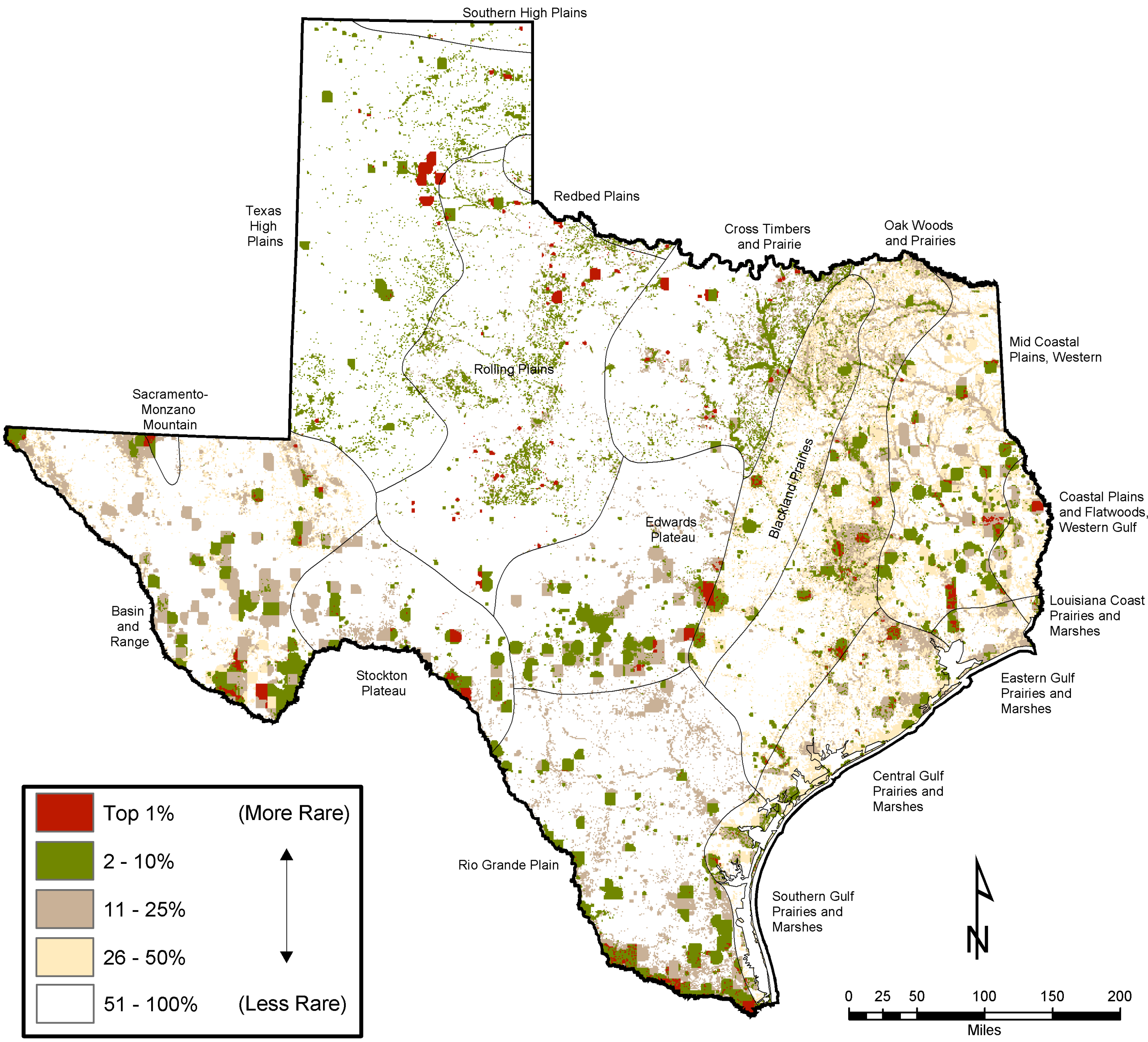

Figure B. Map of the rarity layer with ecoregion boundaries. This map is a composite of four sub-layers: vegetation rarity, natural heritage rank, taxonomic richness, and rare species richness.

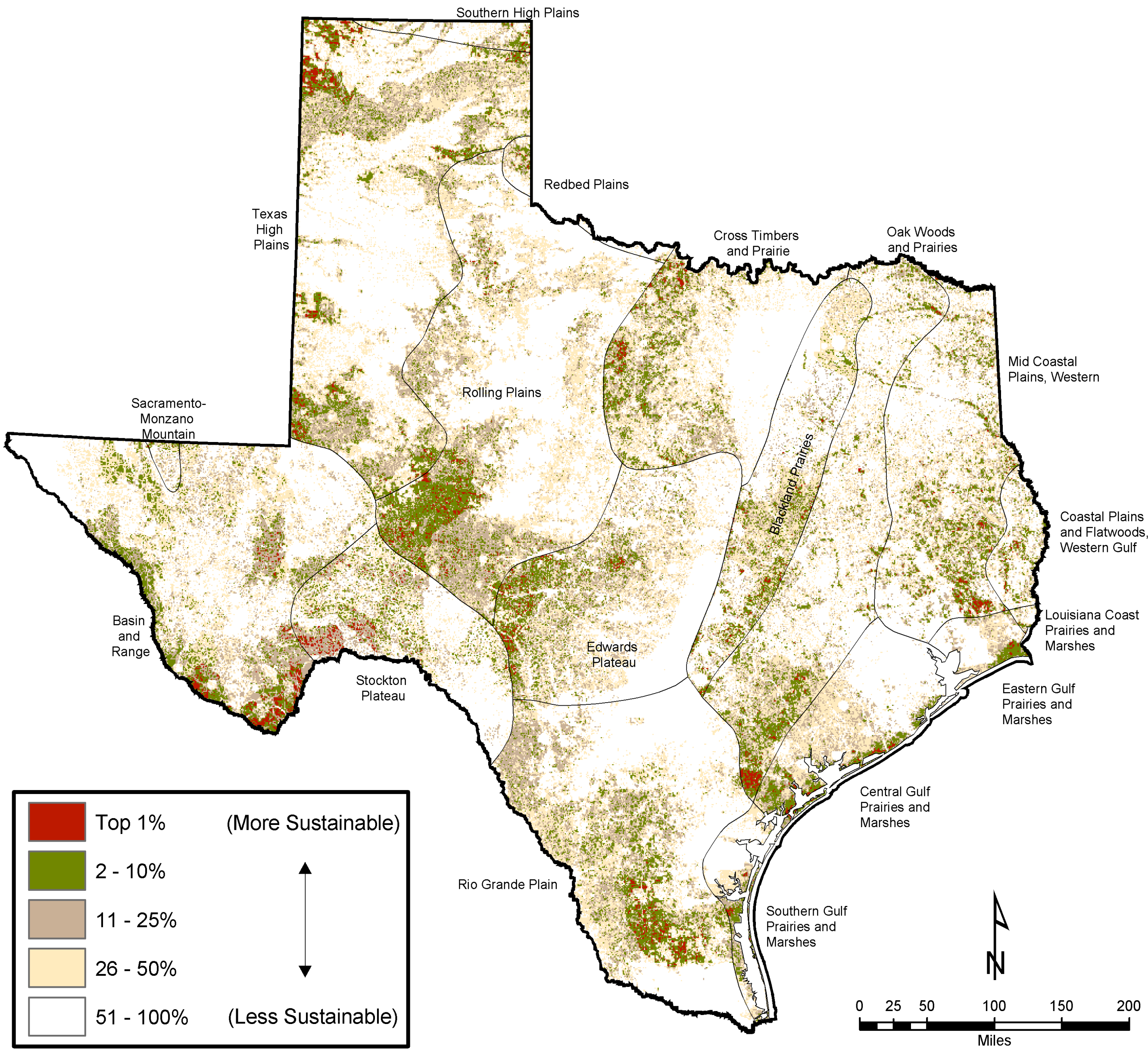

Figure C. Map of the sustainability layer with ecoregion boundaries. This map is a composite of eleven sub-layers: contiguous land cover type; regularity of ecosystem boundary; appropriateness of land cover; waterway obstruction; road density; airport noise; Superfund NPL and state Superfund sites; water quality; air quality; RCRA TSD, corrective action, and state VCP sites; and urban/agriculture disturbance.

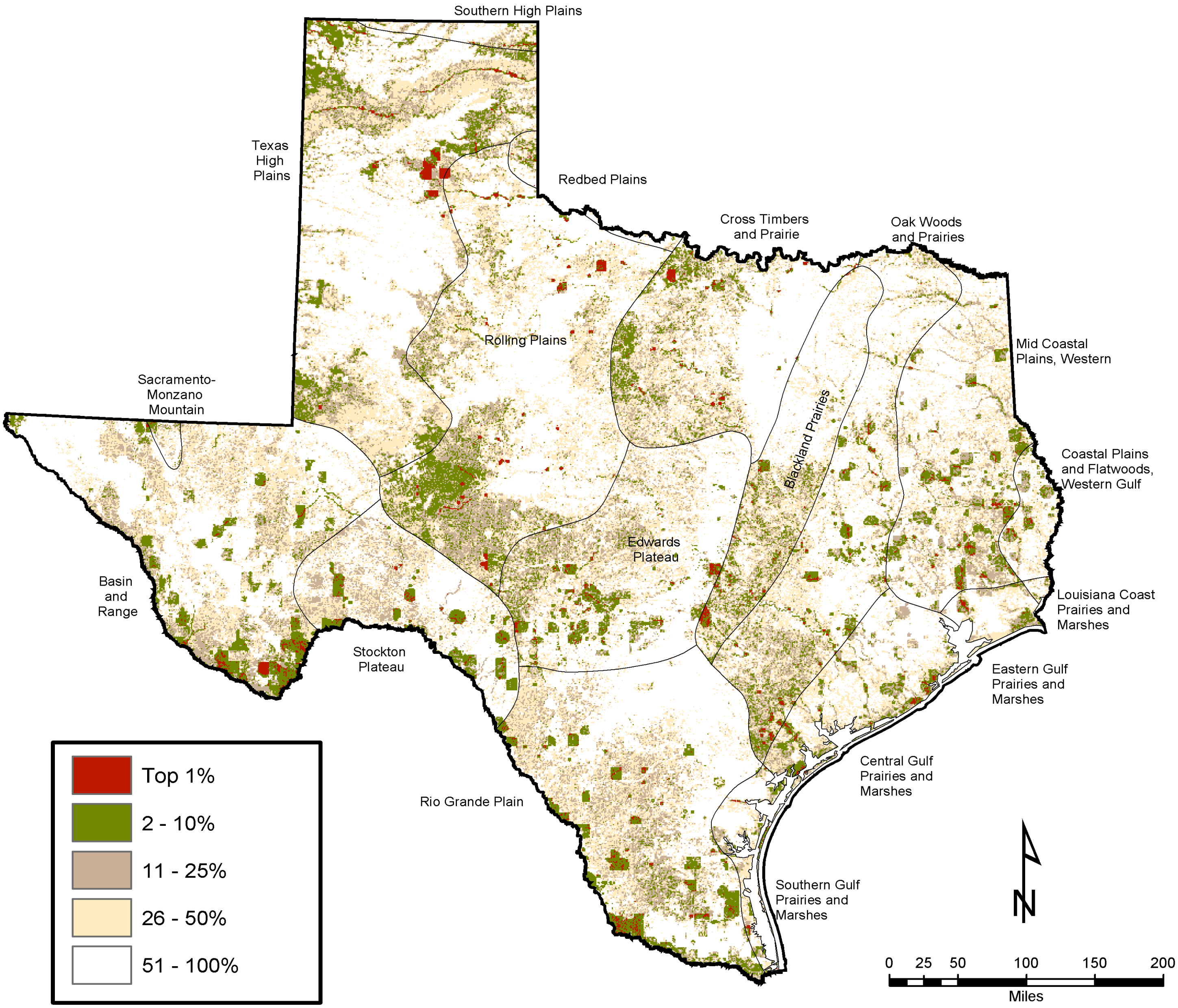

Figure D. Composite map with ecoregion boundaries. This map is a composite of the diversity layer (Figure A), rarity layer (Figure B), and sustainability layer (Figure C).

1.0 INTRODUCTION

1.1 TERS History

Texas Environmental Resource Stewards (TERS) was established by various state and federal resource agencies in July 2002 to create greater interagency collaboration on identifying and supporting joint priorities in Texas. Leaders from the U.S. Environmental Protection Agency (EPA), U.S. Army Corps of Engineers (USACE), U.S. Fish and Wildlife Service (FWS), Federal Highway Administration (FHWA), Texas Commission on Environmental Quality (TCEQ), Texas Parks and Wildlife Department (TPWD), Texas Department of Transportation (TXDOT), and the Texas Governor's Office met to develop a vision and objectives for TERS. Other target participants, such as the General Land Office (GLO), Texas Water Development Board (TWDB), Texas Historical Commission (THC), Texas Department of Agriculture, U.S. Forest Service (USFS), and non-governmental organizations (NGO's), such as The Nature Conservancy of Texas (The Conservancy) were also identified as possibly having an interest in supporting the TERS vision and goals. The Conservancy was subsequently asked to participate because of its expertise in producing ecoregional portfolios of important conservation areas.

Participating agencies identified common interests and target activities for collaborative ecosystem evaluation and management in Texas. Common interests and uses included identification of ecologically important areas (wetland, aquatic, and terrestrial) to be targeted for avoidance, minimization of impacts, or compensatory mitigation (enhancement, preservation, or restoration); "streamlining" of regulatory processes; generation of additional data to support regulatory decisions; early assistance with National Environmental Policy Act (NEPA) planning and analysis, project development and review; greater collaboration on environmental planning and public outreach; analysis of cumulative impacts (also including direct, indirect, and secondary impacts); preservation and improvement of surface water, ground water, and air quality; identification of ecologically important habitats (wetland, aquatic, terrestrial, endangered species); and providing improved indicators of biodiversity health and ecosystem functionality (including fragmentation effects). Streamlining, as defined in this report, is a cooperative and coordinated process that assures timely, cost effective, and environmentally sound planning and project development based on concurrent, multi-agency review. Executive Order (EO) 13274, Environmental Stewardship and Transportation Infrastructure Project Reviews, suggests agencies take actions to expedite environmental reviews and permit decisions specifically for transportation projects.

The following vision was developed for TERS:

> Improve mutual understanding of agency needs and expectations.
>
> Use collective knowledge and expertise to broaden perspectives and support decision-making affecting regional environmental, economic and societal policies, issues, and trends.
>
> Strive for synergism, so that the total effect is greater than the sum of individual agency efforts.

The initial goals of TERS were to identify ecologically important areas, identify potential mitigation areas, and streamline regulatory processes. The TERS agency representatives chose to focus solely on environmental and ecological conditions, not historical and cultural resources. This report is the initial step in meeting the first TERS goal: the ecological assessment and identification of ecologically important resources in Texas.

1.2 Texas Ecological Assessment Protocol (TEAP) Goals

The approach to achieving the TERS vision was to identify and collaborate on common priorities using an ecosystem approach to organize strategies that achieve effective and measurable environmental results, and to jointly communicate the results to the public. The TEAP is the method the TERS Steering Committee agreed to (1) develop a scientifically valid, ecosystem-based process for Texas; (2) apply this process to existing available data and information through the use of Geographical Information Systems (GIS); and (3) demonstrate the process for identifying ecologically important resources throughout Texas. TERS participants were asked to identify potential uses for the TEAP within each agency. However, at the present time, no specific commitments or plans for the TEAP have been made.

The TEAP is a screening level, rapid assessment tool using existing electronic data available statewide. The TEAP is an "ecoregional" assessment, applied to an entire state. Therefore, it is general in nature and design. It is a planning tool and screening-level assessment that should lead users to progressively narrow the scope of analysis. It is not an all-encompassing predictive model for each land cover type, species, etc.

The potential intended use of the results of the TEAP include: 1) use in the NEPA planning process (scoping, alternatives development, etc.), 2) use in streamlining the authorization process for large projects (such as transportation) by narrowing the study corridor necessary for further field investigation, and 3) use in mitigation discussions to avoid ecologically important areas, minimize impacts to those areas, and compensate for unavoidable impacts. This list of intended uses is not exhaustive, nor all inclusive. The TEAP is not designed to take the place of agency policies and procedures. It is a supplemental information tool aiding in agency decision making. The initial TEAP product is a CD with the three main layers and composite layer data in GIS format. The final version of this report will be included on the CD.

1.3 Background

1.3.1 Geographical Information System (GIS)-Based Assessments

GIS is used in the development of assessment and geospatial screening tools not only because of its spatial data visualization abilities (i.e., maps of different data layers, coverages, landscape level, etc.), but also because of its modeling and analysis functions, including landscape metrics (e.g. FRAGSTATS), and other calculations such as population density, hydrological function. Given the direction of the TERS executives, it was apparent that GIS would be useful for TEAP. GIS is a vital research and assessment tool (Dale et al. 1994, Treweek and Veitch 1996, O'Neill et al. 1999, Iverson et al. 2001, Clevenger et al. 2002, Ji and Leeberg 2002). When used at the landscape level, GIS can identify and prioritize areas for protection to enable animal movement by evaluating different land management uses (Clevenger et al. 2002).

Regionally-scaled projects, such as those that use the ecoregion (Mysz et al. 2000) or watershed (Dickert and Tuttle 1985, Tinker et al. 1998, Espejel et al. 1999, Steiner et al. 2000a, Steiner et al. 2000b, Serveiss 2002) as a base unit, have become more common with the advent and subsequent increase in the use of spatial analysis tools such as GIS. These tools have inspired scientists concerned about landscape level patterns and their effect on terrestrial and aquatic communities (Steiner et al. 2000a, Jones et al. 2001, H. John Heinz III Center for Science, Economics and the Environment 2002). Assessments, whether landscape- or geographically-based, are more holistic than assessments performed locally, or those based on political boundaries, because of their ability to relate potentially unrelated factors (Miller et al. 1998) and for comparisons at other scales. For example, several geographic units can be aggregated (Montgomery et al. 1995).

Geographically-driven approaches have also been used to analyze environmental problems (e.g. nonpoint source water pollution, regional studies) that do not fit into traditional programs or assessment methods (Boughton et al. 1999, Serveiss 2002,) as well as those problems needing a holistic or comprehensive analysis such as broad assessments like TEAP. Landscape-level assessments also lead to improved intergovernmental coordination and more informed decision-making on regulatory and management initiatives (Steiner et al. 2000a, Serveiss 2002). Better interagency coordination and cooperation are goals of the TERS group.

As with TEAP, most geospatial tools use some sort of criteria or factors to evaluate the data layers used in the assessment (Karydis 1996, Steiner et al. 2000b, Store and Kangas 2001, Xiang 2001). These ranks, or scores, simplify the analysis (Serveiss 2002), normalize disparate data sets onto one nominal scale (Wickham et al. 1999, Clevenger et al. 2002), and provide an easily understandable format to communicate the results to various audiences (Theobald et al. 2000). These 'scores' are helpful in comparing various aspects of projects since the 'score' represents the relative value of one alternative to another (Abbruzzesee and Leibowitz 1997, Wickham et al. 1999, Steiner et al. 2000b). These scoring systems may represent the difference between an ideal state of the environment and reality (Tran et al. 2002).

1.3.2 Ecoregion Delineation

TEAP uses eighteen ecoregion sections (hereafter referred to as ecoregions) developed by Bailey (1994) as the base unit for calculation. Further details on the process of base unit selection are provided in the Methods chapter. Ecoregions illuminate ecosystem patterns at multiple scales, aiding the visualization of differences between ecosystems. They can be defined as regions of relative homogeneity in ecological systems (Griffith et al. 1999). Most ecoregions include minimally impacted areas that can be used to define reference conditions necessary to provide a basis for comparison to impacted areas. Since multiple areas within an ecoregion are relatively similar, they should respond similarly to stresses or management actions. Thus, ecoregions are appropriate areas for extrapolation of monitoring, including statistical sampling or research results (Bryce et al.1996, Harrison et al. 2000). Ecoregions can be used as reporting frameworks that clarify patterns of environmental data (such as nutrient transport) reflecting both natural and human influences. Griffith et al. (1999) contend that ecoregion frameworks are highly effective tools for accomplishing comprehensive and integrative management approaches due to their depiction of the whole mosaic of ecosystem components - biotic and abiotic, terrestrial and aquatic, including human-related factors that affect water quality and quantity (major components of watershed assessment).

Ecoregions allow the development of management strategies appropriate to regional expectations. They define areas where standardized management practices can be applied after being proven in individual sites or watersheds.

1.3.2.1 Types of Ecoregion Delineation

Bailey (1985, 1987, 1994, 1996) developed a multi-tiered, broad-scale, hierarchical system of ecoregions at a scale of 1:7,500,000 based on numerous environmental variables (Figure 1). The first two tiers are based on combinations of climate, physiography, topography and soils which were used to provide a general description of the ecosystem geography. The ecoregion system can be used to address environmental issues that transcend agency, watershed, and political boundaries and borders. Details of the ecoregion sections in Texas can be found in Appendix A. Other delineations of ecoregions include Omernik (1987, 1995) (Figure 2), Gould (1975) (Figure 3), and Lyndon B. Johnson School of Public Affairs (1978) (Figure 4). The Omernik (1987) system constructs ecoregions based on perceived patterns of a combination of causal and integrative factors including land use, land surface form, potential natural vegetation, and soils (Omernik 1987). Bailey (1994, 1996) and Omernik (1987) plan to merge ecoregion maps. The map of vegetative types of Texas (Gould 1975) provides a checklist and ecological summary of Texas plants (Figure 3).

An interdisciplinary team of scientists and laymen developed a system of classifying Texas into natural regions (Lyndon B. Johnson School of Public Affairs 1978). They recognized that regions distinguished by physiographic or biologic differences could be readily identified by scientists and local citizens, with the goal of preserving elements of Texas' natural diversity (Figure 4).

1.3.3 Ecological Theory Used in TEAP

TEAP divides nineteen individual measures from databases into sub-layers which comprise three separate main layers. These main layers are diversity, rarity, and sustainability.

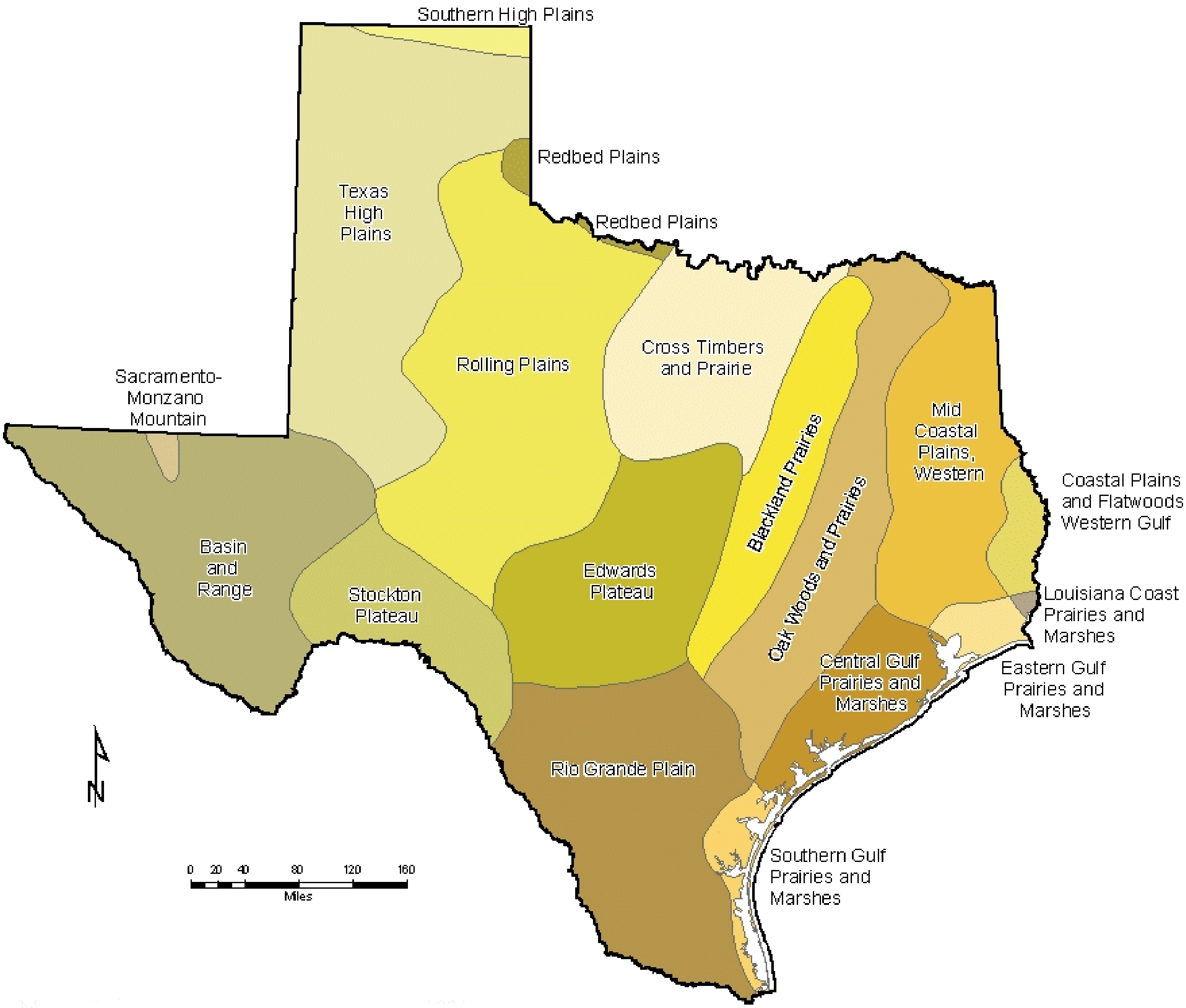

Figure 1. Map of Bailey's ecoregion sections (Bailey 1994).

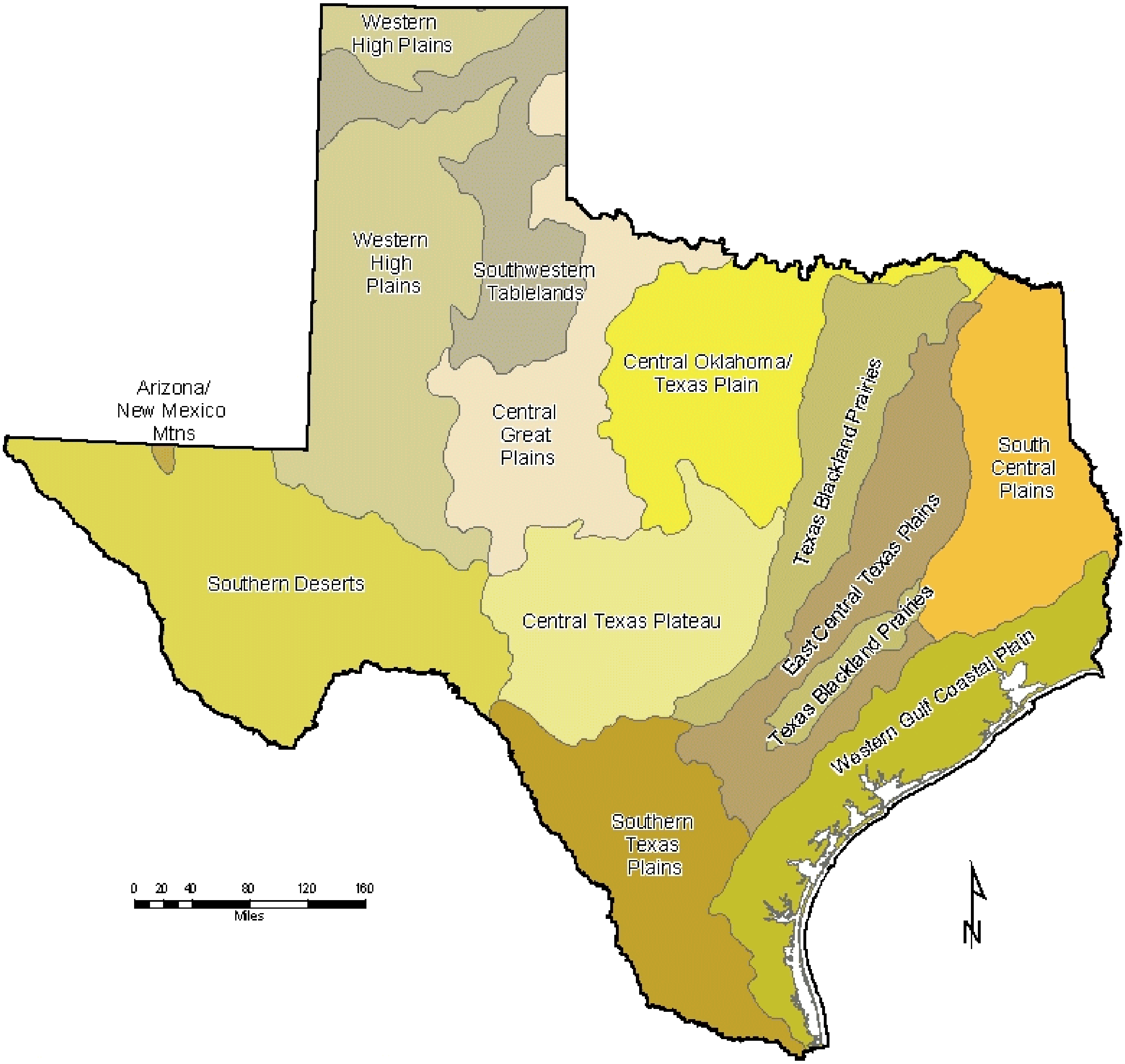

Figure 2. Map of Omernik ecoregions (Omernik 1987).

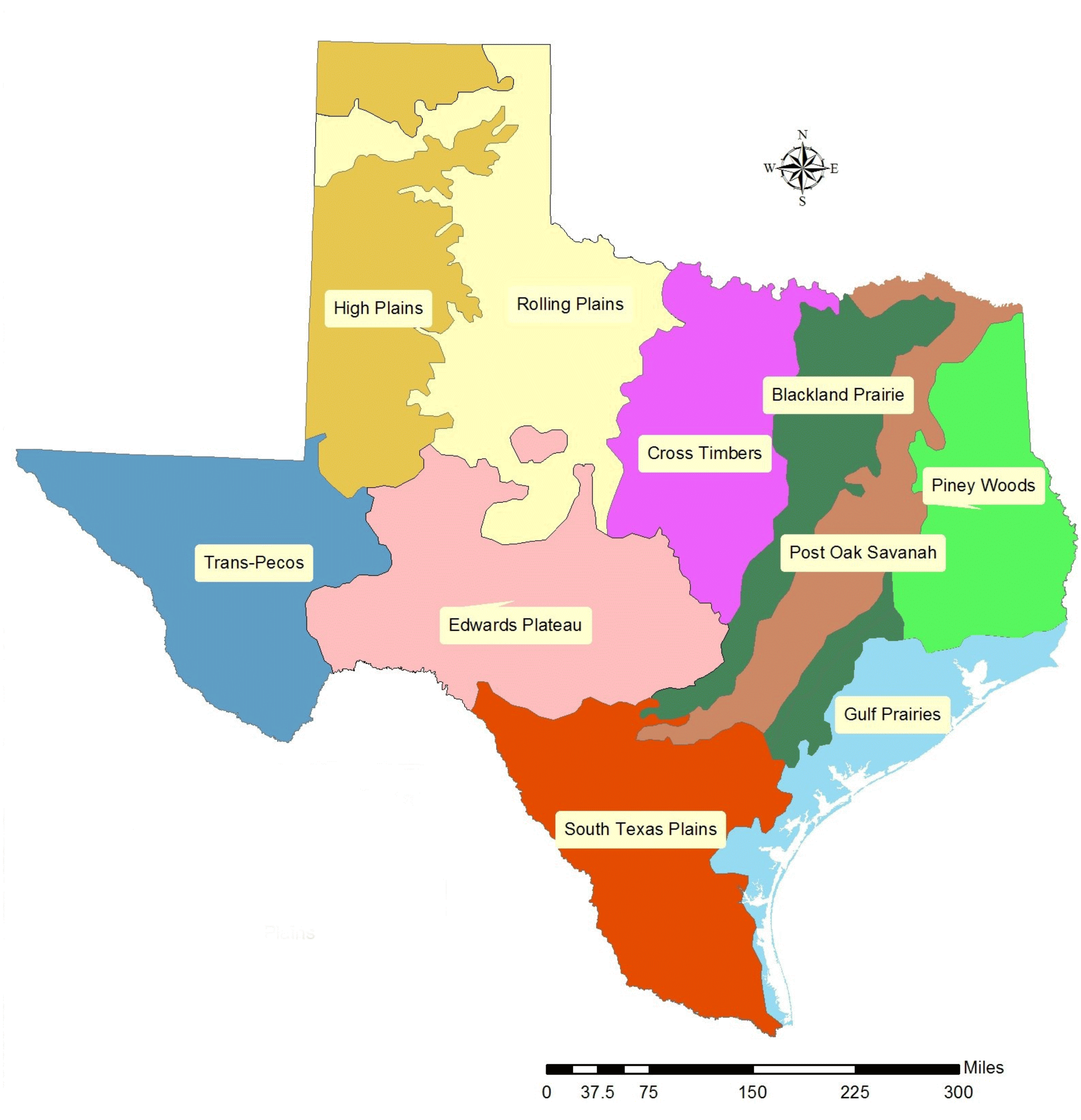

Figure 3. Map of Gould's vegetation types (Gould 1975).

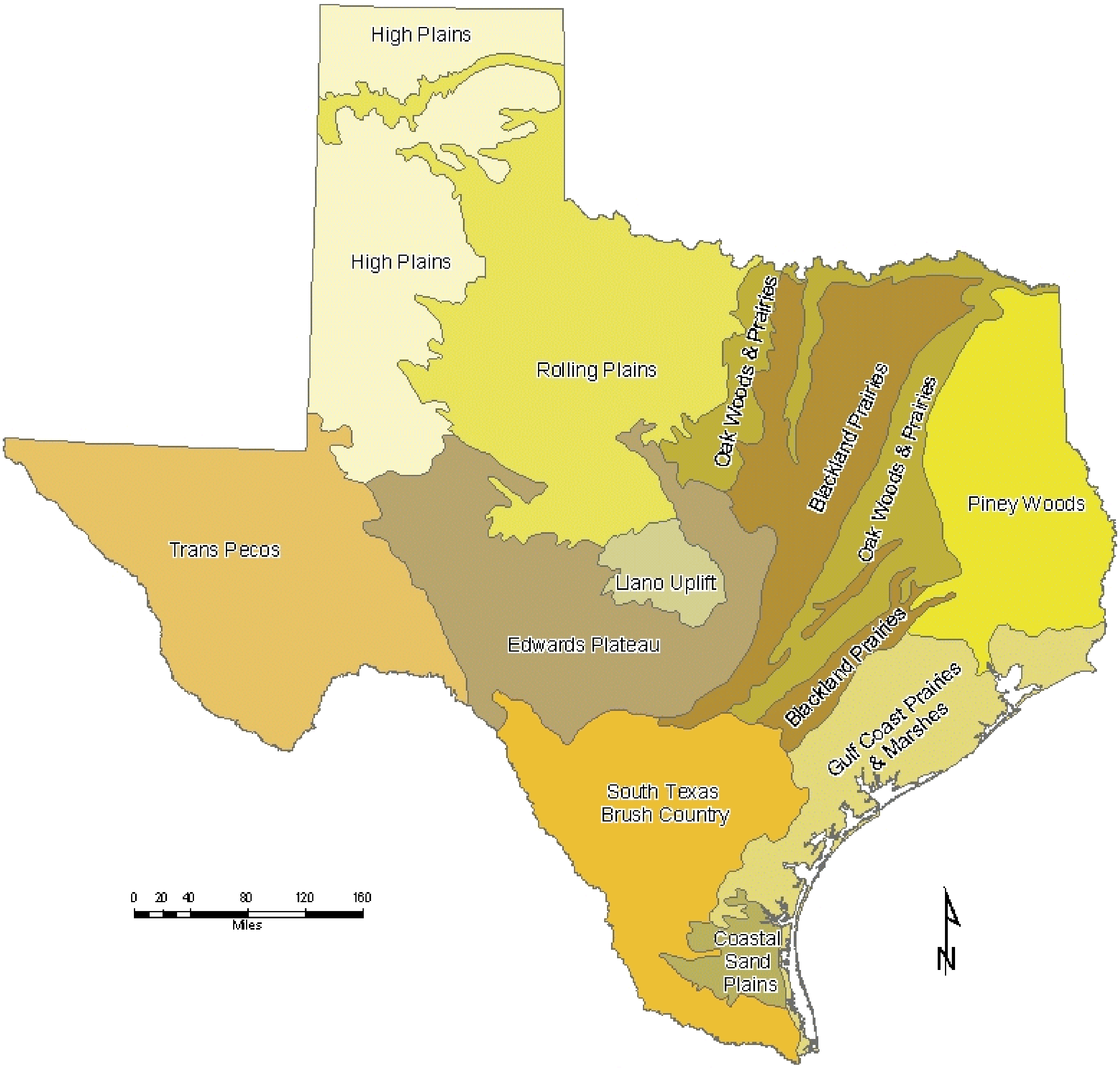

Figure 4. Map of Texas natural areas (Lyndon B. Johnson School of Public Affairs 1978).

1.3.3.1 Diversity

The diversity layer shows land cover continuity and diversity in Texas. This layer consists of four sub-layers: (1) appropriateness of land cover, (2) contiguous size of undeveloped area, (3) Shannon land cover diversity, and (4) ecologically significant stream segments.

The diversity layer demonstrates an important fundamental ecological principle: the species-area relationship. The species-area relationship states that larger areas have higher diversity and/or species abundance than smaller areas (Diamond and May 1976, Schafer 1990, Harte and Kinzig 1997). There are several hypotheses to explain the species-area relationship. The one pertinent for TEAP is the habitat diversity hypothesis, which states that increases in the number of types of habitat in an area increases the number of niches able to be filled, therefore larger areas would have more species or land cover types (Jonson and Fahrig 1997). Other species-area hypotheses include island biogeography (MacArthur and Wilson 1967) and the random sample hypothesis (Arrhenius 1921).

1.3.3.1.1 Appropriateness of Land Cover. Appropriateness of land cover describes the predicted natural vegetation under no human influence (Kuchler 1964) and compares it to the current vegetation cover. The rationale for including this measure in the diversity layer is twofold: 1) the area is ecologically stable and resistant to disturbance if pre-settlement vegetation and current vegetation types are the same, and 2) it is a surrogate for species diversity.

1.3.3.1.2 Contiguous Size of Undeveloped Land. Contiguous size of undeveloped land is calculated using the theory that the larger the contiguous area of undeveloped land, the higher the diversity (MacArthur and Wilson 1967, Dale and Haeuber 2000).

There are two similar measures calculated in the diversity and sustainability layers. "Contiguous area of undeveloped area" is entitled and calculated slightly differently in the diversity layer compared to the sustainability layer. In the diversity layer, all undeveloped land cover types that are adjacent to each other are lumped into one polygon. In the sustainability layer, the individual, undeveloped land cover types (that made up this larger polygon in the diversity layer) are calculated separately. In diversity, the question being answered is, "how extensive are the areas of undeveloped land?" In sustainability, the question answered is, "How extensive are the cover types that make up the areas of undeveloped land?"

All adjacent undeveloped land cover is merged into one polygon (e.g., forest adjacent to wetland adjacent to grassland). One polygon could have any number of cover types. For example, one contiguous polygon may consist of three different, undeveloped land cover types. As long as they are all undeveloped and adjacent to each other, the contiguous size of undeveloped land sub-layer is calculated as one polygon (until interrupted by a developed cover type).

1.3.3.1.3 Shannon Land Cover Diversity Index. The Shannon land cover diversity index calculates the diversity, in terms of land cover types, for each of the contiguous polygons calculated in the previous section. The Shannon index is an established method used to measure ecological (species) diversity (richness and evenness) (Begon et al. 1986). It usually calculates the proportion of individuals of a population related to the total number of individuals, but used here to calculate the proportion of land cover types, related to the total number of land cover types. Other ecological diversity measures used in landscape assessment are discussed in Herzog et al. (2001).

The Shannon land cover diversity index does not view land cover diversity the same way as the contiguous size of undeveloped land sub-layer. In general, the Shannon land cover diversity index shows how many specific land cover types there are in these contiguous area polygons and how they are dispersed.

A low value for Shannon land cover diversity index means there are fewer undeveloped land cover types and that they may be clumped, compared to a more evenly dispersed pattern within the geographical boundary. A high value would indicate that there are several undeveloped land cover types that are more evenly dispersed throughout the geographic area. The idea that the Shannon land cover diversity index should increase with less contiguous area is not exactly true because the measures are somewhat independent. Logic indicates that it may be more likely that there are more land cover types in larger areas (polygons), but that is not necessarily the case. For example, there could be a large unbroken tract of desert in west Texas.

1.3.3.1.4 Ecologically Significant Stream Segments. Significant stream segments (Norris and Linum 1999, El-Hage and Moulton 2000a, Norris and Linum 2000a, El-Hage and Moulton 2000b, Norris and Linum 2000b, El-Hage and Moulton 2001) represent natural systems that are increasingly rare habitat and is the aquatic equivalent of the contiguous size of undeveloped land sub-layer. Significant stream segments are ecologically unique areas determined by TPWD based on biological function, hydrologic function, riparian conservation areas, high water quality (including aquatic life and aesthetic value), and threatened or endangered species. TPWD used scientific literature, existing data, and TPWD expertise to identify 228 segments meeting at least one of the criteria listed above.

Stream or river segments are considered significant using five criteria: 1) biological function, where segments display a high level of biodiversity, age, and uniqueness; 2) hydrologic function, where segments perform valuable functions related to water quality, flood attenuation, flow stabilization, or ground water recharge; 3) riparian conservation areas, which includes state and Federal refuges, wildlife management areas, preserves, parks, and mitigation areas; 4) high water quality/exceptional aquatic life/high aesthetic value that represents unique or critical habitat or exceptional aquatic life; and 5) threatened and endangered species/unique communities where segments represent the presence of unique, exemplary, or unusually extensive natural communities.

The ecologically significant stream segment designation is not the same as the ecologically unique stream segment designation. The former has no legal status, but the later represents a statutorily defined legal category. The criteria used for both stream definition types are identical in many respects. The act of officially designating a stream segment as “ecologically unique” is a combined effort of TPWD, TWDB, and the Texas legislature and does not protect the segment from physical degradation. It prevents a state agency from obtaining a fee title or easement that would compromise the ecological value of the designated stream segment. Designation of a segment recognizes the importance of protecting the ecological legacy of Texas' rivers and streams.

1.3.3.2 Rarity

The rarity layer was designed to show rarity of species and land cover in Texas. The rarity layer consists of four sub-layers: (1) vegetation rarity, (2) natural heritage rank, (3) taxonomic richness, and (4) rare species richness.

1.3.3.2.1 Vegetation Rarity. The land cover or vegetation rarity measure is derived from the U. S. Geological Survey (USGS) National Land Cover Dataset (NLCD) and represents rarity of all natural cover types including water and bare rock. Vegetation rarity is a measure of the particular land cover types that are considered rare within each ecoregion.

1.3.3.2.2 Natural Heritage Rank. The Global Heritage Ranking System created by The Conservancy is described as:

> G1, S1, Critically imperiled. Critically imperiled globally (G) (or in the state, S1) because of extreme rarity or because of some factor(s) making it especially vulnerable to extinction. Typically, this rank consists of five or fewer occurrences or very few remaining individuals (< 1,000) or acres (< 2,000) or linear miles (< 10).
>
> G2, S2, Imperiled. Imperiled globally (or in the state, S2) because of rarity or because of some factor(s) making it very vulnerable to extinction or elimination. Typically, this rank consists of 6-20 occurrences or few remaining individuals (1,000-3,000) or acres (2,000-10,000) or linear miles (10-50).
>
> G3, S3, Vulnerable. Vulnerable globally (or in the state, S3) either because they are very rare and local throughout its range, or found only in a restricted range (Even if abundant at some locations), or because of other factors making it vulnerable to extinction or elimination. Typically, this rank consists of 21 to 100 occurrences or between 3,000 to 10,000 individuals.

G4, S4, Apparently secure. Uncommon globally (or in the state, S4), but not rare (although it may be rare in parts of its range, particularly on the periphery), and usually widespread. Apparently not vulnerable in most of its range, but possible cause for long-term concern. Typically, this rank consists of more than 100 occurrences and more than 10,000 individuals.

G5, S5, Secure. Common globally (or in the state, S5), widespread, and abundant (although it may be rare in parts of its range, particularly on the periphery). Not vulnerable in most of its range. Typically, this rank consists of with considerably more than 100 occurrences and more than 10,000 individuals.

1.3.3.2.3 Taxonomic Richness. Taxonomic richness, or the number of rare taxa is another measure of rarity. This sub-layer measures the richness of broad taxonomic groupings; that is, the locations that have a high degree of rarity in multiple taxa, e.g., birds, mammals, reptiles, amphibians, etc. The number of rare taxa (taxonomic richness) indicates taxonomic diversity.

1.3.3.2.4 Rare Species Richness. Another measure of rarity is rare species richness, or the number of rare species per ecoregion. The number of rare species (rare species richness) may indicate the amount of endemism in an area. Rare species may be keystone/umbrella species (Launer and Murphy 1994) or very productive communities or typify a particular ecological community type (Poiani et al. 2001).

1.3.3.3 Sustainability

The sustainability layer describes the state of the environment in terms of stability; that is, how resistant to disturbance an area is, and how capable is the area in returning to its pre-disturbance state, that is, resilience (Begon et al. 1986). For the purposes of this report, sustainable areas are those that can maintain themselves into the future without human management.

Stability has two components: resistance and resilience. Resistance is defined as an ecological community's ability to withstand disturbance (Begon et al. 1986), whereas resilience is the ability of an ecological community to recover from a disturbance (Begon et al. 1986). Highly sustainable ecosystems are able to resist disturbance, but once disturbed can return to the pre-disturbance state within a short time period (resilience) (Begon et al. 1986). The sustainability layer consists of eleven measures that can be loosely grouped into fragmentors: (1) contiguous land cover type, (2) regularity of ecosystem boundary, (3) appropriateness of land cover, (4) waterway obstruction, and (5) road density and stressors: (1) airport noise, (2) Superfund National Priority List (NPL) and state Superfund Sites, (3) water quality, (4) air quality,(5) Resource Conservation and Recovery Act (RCRA) Treatment-Storage-Disposal sites (TSD), corrective action and state Voluntary Cleanup Program (VCP) Sites, and (6) urban/agricultural disturbance.

1.3.3.3.1 Contiguous Land Cover Type. Contiguous land cover is based on the principle that larger areas having similar ecosystem types have greater sustainability. Contiguous area of undeveloped land supports connectivity, the opposite of the isolating effects of fragmentation (Gustafson and Gardner 1996). Larger habitat areas have less edge than smaller habitat areas and therefore, can preserve biodiversity (Lee et al. 2001). Larger areas of contiguous habitat can support large animals or widely-dispersing animals such as carnivores and large ungulates. As these large areas are fragmented, either through direct habitat loss or through insularization, the remaining habitat may not maintain viable population of these organisms (Tigas et al. 2002).

Fragmentation of habitats comprises two ecological effects: 1) loss of habitat, and 2) increased insularization (or isolation) of the remaining habitat (Noss and Csuti 1994). It is a spatial phenomenon that affects landscape continuity (Robinson et al. 1992) and poses some of the most significant challenges to ecologists. It is a major threat to landscape continuity and can disrupt temporal and spatial habitat use by animals (Tigas et al. 2002). The effects of fragmentation have been demonstrated for a variety of taxa: mammals (Brown 1986, Foster and Gaines 1991, Chiarello 1999, Lindenmayer et al. 1999); birds (Askins et al. 1987, Opdam 1991, Walters et al. 1999); reptiles and amphibians (Johnson 1986, Vos and Stempel 1995); and insects (Johnson 1986, Thomas and Harrison 1992, Wahlberg et al. 1996).

1.3.3.3.2 Regularity of Ecosystem Boundary. For all land cover types except open water, conventional ecological wisdom suggests that the smaller the perimeter for a given area, the larger the core interior habitat. It is based on the principle that the least amount of boundary results in the lowest amount of “edge effect” thereby yielding the least disturbance and greatest sustainability of the ecosystem. The reverse is also true; areas with larger perimeters compared to their areas, will have a greater amount of “edge” habitat and less “interior” or core area. The more complex the edge, the more opportunities for negative influences to affect the location. The more negative influences, the less sustainable the location. Habitat edges differ from the interior in their ecological processes (Donovan et al. 1997) and in physical impacts, such as changes in vegetation density, size, shape, matrix habitat, and fragment aggregation. Small patches may have properties similar to the edge throughout.

The measure of regularity of ecoregion boundary reflects the perimeter to area ratios (PAR) of areas of particular land cover types. Ecological theory suggests that perfectly circular or square habitat areas will have higher diversity and/or species abundance compared to linear habitat areas (Game 1980). However, small narrow areas may provide erosion control to riparian areas (H. John Heinz III Center for Science, Economics and the Environment 2002). Habitat edges differ from the interior in their ecological processes (Donovan et al. 1997) including physical impacts, such as changes in vegetation density, size, shape, and matrix habitat (Lidicker 1999). Biological impacts to species (Yahner 1988) are well documented. Edges are transition zones where generalist species thrive. Conventional ecological wisdom concerning "edge" demonstrate that invasive or opportunistic species prefer the types of habitat associated with the "edge," or the boundary between two habitat types (H. John Heinz III Center for Science, Economics and the Environment 2002). As one moves away from the edge there is a change in species composition (Lee et al. 2001) which can be associated with abiotic factors, such as temperature, humidity, and vegetation structure (McCollin 1998). Unique or rare species typically use "interior" habitat or may need a large amount of habitat as a home range.

There are many examples concerning edge-interior species. For example, cowbirds and other parasitic birds prefer the habitat on the agriculture-forest boundary and prey on birds, such as the black-capped vireo or golden-cheeked warbler, that need a certain amount of habitat away from this boundary, or interior habitat. Many birds, including warblers and red-cockaded woodpeckers require forest interior habitat. Large-bodied animals, such as bears and mountain lions, may need extended habitat areas in which to forage and mate, without the intrusion of urban or agricultural activities (Noss and Csuti 1994). Forest areas adjacent to non forest areas may by more affected by abiotic elements (e.g., wind, heat) and consequently open to invasion by exotic species (H. John Heinz III Center for Science, Economics and the Environment 2002).

It is widely accepted that the nature of patch edge in aquatic and terrestrial systems differs greatly due to high differences in the land cover types (water vs land) and differences in the nature of communities of the interface zones. A more convoluted water/land edge allows for a greater amount of habitat suitable for the species and communities that live (and often can only exist) in these interface zones. At the most general level, this land/water edge differs from the edge between two (or more) terrestrial land cover types because of the difference in the cover type media (i.e. water vs. land). There is less transfer in species, materials and energy between these two patch types (i.e., there is less invasion possible either from water to land or vice versa, and thus less deleterious "edge effect." The term "edge effect" is not widely used in the literature for water/land boundaries compared to the description of dynamics between terrestrial land cover patches.

As habitat areas become more fragmented and insularized, the edge habitat tends to increase and the interior habitat tends to decrease; therefore, impacting the sustainability of rare or unique species. Because of internal modifications and the lack of intact core areas, small patches may have properties similar to the edge. A preference for the edge results in a negative response to habitat area because large habitat areas have smaller PARs than small habitat areas (Cappuccino and Root 1992). Studies describing habitat "shape" are related to edge effects through the PAR (Collinge 1996, 1998, Collinge and Forman 1998). In addition, island biogeographic theory (MacArthur and Wilson 1967) has been used to generate the following "optimum" characteristics for land and species conservation: large circular, undivided sites (or "reserves"), or if the site is divided, then connectivity by corridors (Wilson and Willis 1975, Diamond and May 1976, Burel 1989) based on these shape and "edge effect" theories.

1.3.3.3.3 Appropriateness of Land Cover. Appropriateness of land cover describes the predicted natural vegetation under no human influence (Kuchler 1964) and compares it to the current vegetation cover. The rationale for including this measure in the sustainability layer is that if pre-settlement and current vegetation types are similar then the seed bank is intact and therefore the area can recover from a disturbance more quickly (resilience).

1.3.3.3.4 Waterway Obstruction. The waterway obstruction sub-layer is based on the principle that dams and corresponding reservoirs are interruptions to the continuity of waterways. Waterway obstruction is a surrogate for fragmentation to water bodies. Dams disturb the natural flow regime of a river, turning it into a reservoir and non-flowing system. The river environment, both aquatic and riparian, is fragmented and insularized, thus creating disturbances for the fish, aquatic organisms and plant communities associated with this habitat.

1.3.3.3.5 Road Density. The road density sub-layer is based on the principle that roads fragment the landscape (Abbitt et al. 2000). In general, more roads and larger roads (multilane highways, for example) occur near the population centers and also serve to connect them. The higher the density of roads, the more fragmentation and disturbance occurs to natural communities (Abbitt et al. 2000).

1.3.3.3.6 Airport Noise. The airport noise sub-layer is based on the principle that noise around airports stresses surrounding habitats thereby lowering the quality of wildlife habitat. Airport noise is a disturbance to natural communities based upon the noise level from airplanes and associated activities, maintenance on the runways themselves, and because they serve as a catalyst for development surrounding the airport. Airports with larger runways typically have wider areas of disturbance.

Aircraft noise is known to impact wildlife patterns especially those of birds (e.g., feeding, resting and nesting) and to increase predation on amphibians has been observed. According to the Federal Aviation Administration (FAA), the noise generated by an aircraft is generally determined by the thrust powering the aircraft; the amount of thrust an aircraft needs is proportional to the weight of the plane. That is, the heavier the aircraft, the more thrust it needs and the more noise is produced. Runway length only defines the heaviest aircraft (total weight) that can land and take off. While newer aircraft have shorter runway length take off requirements and reduced noise, many of the older aircraft (e.g., 747 and Lear 25) with high noise potential remain in service. The buffer distance around airports was used as an indication of disturbance due to noise. To estimate the distance, the noise disturbance was assumed to be proportional to the size of the aircraft, and that was proportional to the runway length.

1.3.3.3.7 Superfund National Priority List (NPL) and State Superfund Sites. These are sites where hazardous substances have been released and are, by definition, disturbances or stressors on the natural environment. While efforts are made to minimize the impacts of these sites and to clean up or contain contaminants to acceptable risk level, the release of toxic chemicals may permanently alter natural conditions. These areas and natural areas adjacent to them are less likely to be self sustaining and more likely to require human management for their continued existence. Once clean up efforts have been completed, further development may be restricted or prohibited at portions of those sites where waste has been left in place in order to prevent disturbance of containment areas and subsequent human exposure. For example, future highway or other construction activities at some sites may need to be avoided. However, with proper engineering, many such sites can and have been put to productive use. As a consequence, unique opportunities for low impact restoration of natural or near-natural habitat areas may be available.

1.3.3.3.8 Water Quality. Water quality or the lack of water quality (defined by Clean Water Act (CWA) Section 303(d), as not meeting designated uses) is another stressor on the natural environment. This sub-layer in no way intends to abrogate any obligations or duties assigned by law to TERS participating agencies.

1.3.3.3.9 Air Quality. Air quality can impact ecological communities due to outfall of chemicals or particulates that become incorporated in the soil of food chain. Poor air quality may be due to mobile sources such as the amount of cars or industrial activities, such as petroleum refining. This sub-layer in no way intends to abrogate any obligations or duties assigned by law to TERS participating agencies.

High concentrations of ozone can have negative effects on flora and fauna (H. John Heinz III Center for Science, Economics and the Environment 2002). Ozone can affect water movement, cycling of mineral nutrients, and habitats for various animal and plant species (EPA 2002). Pollutants such as lead, mercury, and others can be transported and deposited in water or soil where they may be incorporated into the food chain. Nitrogen and sulphur can acidify some water bodies, making them uninhabitable for aquatic species (EPA 2002). Acid deposition can leach nutrients from the soil, consequently affecting plant growth and soil fauna, and enhance the movement of potentially toxic heavy metals, such as aluminum. Deposition of nitrogen can cause eutrophic conditions such as algal blooms and decreased oxygen levels, which in turn may result in fish kills.

1.3.3.3.10 RCRA TSD, Corrective Action and State VCP Sites. These sites are typically smaller than Superfund sites. RCRA TSD sites are active facilities where hazardous wastes are managed on site. RCRA corrective action sites are active TSD facilities which have had releases of hazardous substances and are, by definition, disturbances or stressors on the natural environment. VCP sites are inactive facilities contaminated by various pollutants which typically do not qualify for the state or federal Superfund programs and where a third party wishes to conduct a cleanup in order to redevelop the site. While efforts are made to minimize the impacts of these sites and to clean up or contain contaminants to acceptable risk level, the release of toxic chemicals may permanently alter natural conditions. These areas and natural areas adjacent to them are less likely to be self sustaining and may require human management for their continued existence. Once clean up efforts have been completed, further development may be restricted or prohibited at portions of those sites where waste has been left in place in order to prevent disturbance of containment areas and subsequent human exposure. For example, future highway or other construction activities at some sites may need to be avoided. However, with proper engineering, many such sites can and have been put to productive use. As a consequence, unique opportunities for low impact restoration of natural or near-natural habitat areas may be available.

1.3.3.3.11 Urban/Agriculture Disturbance. This sub-layer is based on the principle that activities in urban and agricultural areas generate disturbances (stressors) to surrounding areas. Stressors such as pesticides, fertilizers, and noise are included.

The urban/agricultural disturbance sub-layer is a surrogate for general population disturbance. These "developed" land cover types are not considered in the calculations in the diversity and rarity layers, but are appropriate in this sustainability sub-layer. The sustainability of an ecological community can be impacted by the amount of human activity, such as those related to agriculture (e.g., pesticide use, nutrient runoff, erosion, etc.) and population (e.g., urban activities including roads, cars, urban sprawl, solid waste, Polycyclic Aromatic Hydrocarbon (PAH) runoff, general environmental contamination, etc.) (White et al. 1996, H. John Heinz III Center for Science, Economics and the Environment 2002, Tigas et al. 2002). Urban uses and agriculture also fragment the community and change natural landscape from desired vegetation types (e.g., wetland, forest, etc.) to undesirable vegetation types (e.g., agricultural monocultures, invasive or opportunistic species) (White et al. 1996, Tigas et al. 2002).

1.3.4 TEAP Development

EPA reviewed over twenty applicable studies and protocols throughout the U.S. (Critical Ecosystems Workshop 2002). TERS participating agency representatives were invited to identify studies and methodologies that could be helpful in addressing objectives and to decide on an appropriate protocol. Reviews resulted in the selection of three protocols for further adaptation and development: (1) processes and information developed in the TPWD Land and Water Resources Conservation and Recreation Plan (Texas Parks and Wildlife Department 2002), (2) information generated by The Nature Conservancy of Texas Ecoregional Planning Process (Groves et al. 2000) and (3) EPA Region 5 Critical Ecosystems Assessment Model (CrEAM) (Mysz et al. 2000, White et al. 2003).

1.3.4.1 TPWD Conservation Planning

TPWD has drafted a strategic plan for ecological and recreational resources for both land and water (Texas Parks and Wildlife Department 2002). TPWD performed an ecoregion priority analysis, using three main criteria: conserved status, primary level of threat, and biological value. Conserved status is determined by the percentage of publicly owned land, land owned by non-governmental conservation groups, large local conserved parkland, and the percentage of the ecoregion operated under TPWD management plans. Primary level of threat is determined by comparing the percentage of land converted to urban or agricultural use, fragmentation of agricultural lands and population growth projections. Biological value is determined by total vertebrate species richness, vascular plant species richness or actual number of species occurring in each ecoregion. Over twenty-two categories of data were collected and mapped. Results by ecoregion are summarized in Table 1.

1.3.4.2 The Nature Conservancy Ecoregional Planning Process

The Conservancy's Ecoregional Planning Process applies a planning and validation process that includes GIS-based analysis, field investigations, and ecological expertise as to endangered community types (Poiani et al. 1998, Groves et al. 2000, Poiani et al. 2001). The

Table 1. TPWD planning results. Priority ecoregions for conservation efforts.

Ecoregion	Priority	Conserved Status	Threats	Rare Plants	Rare Animals
Blackland Prairie	High	Medium	Severely altered	Lowest	Drastic decline
Gulf Coast Prairies & Marshes	High	High	Most threatened	High	Many rare birds in need of attention
South Texas Plains	High	High	High (Lower Rio Grande)	High	Rich bird & butterfly faunas and endangered cats
Cross Timbers & Prairies	Medium	Low	Medium	Low	2 T&E birds
Edwards Plateau	Medium	Medium	Low	Highest	Important for herpetological and invertebrate species
High Plains	Medium	Low	Medium	Low	Numerous birds and other species of concern
Piney Woods	Medium	Medium	High	Low	Highly diverse
Post Oak Savannah	Low	Medium	Low	Low	Several species of concern
Rolling Plains	Low	Low	Medium	One	2 Fed listed 1 state listed
Trans Pecos	Low	Highest	Lowest	Rarest & most unique	Highest percent of vertebrate species of concern

Conservancy uses four criteria to identify and select areas of biodiversity significance: occurrence of conservation elements, functionality of those elements, representativeness, and complimentarity. Conservation elements are those species, natural communities, and ecological systems that are chosen as the focus for conservation within an ecoregion. The Conservancy has completed this process, with multiscale mapping of priority ecological areas for Gulf Coast Prairies and Marshes, West Gulf Coastal Plain, Edwards Plateau, Chihuahuan Desert, Upper West Gulf Coastal Plain, and the Southern Shortgrass Prairie in Texas. The Cross Timbers and Southern Tallgrass Prairie and Tamaulipan Thornscrub were scheduled to be completed by June 2003.

The Conservancy process involved field verification of ecological type and because The Conservancy has not completed its process statewide, The Conservancy data and portfolio conservation areas are to be used in the preliminary accuracy assessment of TEAP results.

1.3.4.3 EPA Region 5 CrEAM

The EPA Region 5 CrEAM (White et al. 2003) model incorporated three key criteria based on established ecological theory: 1) diversity, 2) rarity, and 3) sustainability. Twenty geographically referenced data sets were used to develop indicators for these three criteria. All data sets were pre-existing or derived from pre-existing data sets. Because of the differences in data sets, the CrEAM used 25 acres as its smallest unit of measure. Since TEAP modifies the CrEAM, further details are located in the methods section.

The CrEAM fits within the EPA Science Advisory Board (SAB) ecological framework. In 2002, the EPA Science Advisory Board (SAB) Ecological Processes and Effects Committee released a draft framework for assessing and reporting on ecological condition. The purpose of which was to guide practitioners on designing systems to assess and report ecological conditions. The framework also helps investigators to organize and decide what features to measure for a picture of ecological 'health.' Program goals and objectives are used to determine what essential ecological attributes will be used. There are six broad categories and several subcategories under each: landscape condition, biotic condition, chemical and physical characteristics, ecological processes, hydrology/geomorphology, and natural disturbance regimes. The set of six attributes can be used to determine ecological indicators, or characteristics of ecological systems, and specific measures and monitoring data used to determine the indicator, or endpoint. It is a hierarchical structure where measures can be aggregated into indicators and indicators can be aggregated into attributes. The six attributes are independent of program goals and objectives, but serve as a stimulus for practitioners to decide what attributes and subcategories are essential to a project.

Not every attribute category or subcategory is appropriate in every situation; a user must select those attributes from the SAB framework that provide the best measure and analysis of the project objectives. Table 2 shows the SAB ecological attribute categories, subcategories, suggested measure, and corresponding TEAP criterion. The SAB also suggests that the framework aids in designing the assessment and subsequent report in that it should "transparently record the decision tree and professional judgements used to develop it." The TEAP follows this framework since the measures are aggregated into four broad categories which follow the SAB framework of aggregating measures and indicators; therefore, both single 'media' and aggregate effects (ecological, socioeconomic, etc.) can be considered.

The TEAP allows users to analyze ecological condition, project consequences, and suggest mitigation within watersheds or ecoregions. The TEAP also adheres to the SAB framework by being 1) 'multimedia'; 2) interagency (a repository for coordinating other agencies' data); and 3) understandable to non-scientists by using an intuitive 0 to 100 decision structure.

The SAB also suggests that reference conditions be defined so that ecological indicators can be compared and later normalized for aggregation. This concept is imbedded within TEAP by using a 0 to 100 ranking structure which serves to normalize disparate criteria values.

Table 2. Relationship of the EPA SAB framework ecological attributes to EPA Region 5 CrEAM and TEAP.

ECOLOGICAL PROCESSES			
Category	**Subcategory**	**SAB example measure**	**TEAP criterion**
Energy flow	primary production	tree growth	NONE
	net ecosystem production	CO_2 flux	NONE
	growth efficiency	carbon transfer	NONE
Material flow	organic C cycling	organic matter quality	NONE
	N & P cycling	N-fixation capacity	NONE
	other nutrient cycling	input/output budgets	NONE
LANDSCAPE CONDITION			
Extent of habitat types		perimeter-area ratio	regularity of ecosystem boundary
			contiguous size of undeveloped areas
Landscape condition		number of habitat types	land cover rarity

Category	Subcategory	SAB example measure	TEAP criterion
			land cover diversity
			significant stream segments
			contiguous land cover
Landscape pattern		contagion	appropriateness of land cover
			land cover suitability
			urban & agricultural disturbance
			road density
NATURAL DISTURBANCE REGIMES			
	frequency	recurrence interval	NONE
	intensity		NONE
	extent	spatial extent	NONE
	duration	length of event	NONE
BIOTIC CONDITION			
Ecosystems & communities	community extent	extent of successional state	NONE
	community composition	presence of focal species	number of rare taxa
			number of rare species
			species rarity using G/S rankings
	trophic structure	feeding guilds	NONE
	community dynamics	predation rate	NONE

Category	**Subcategory**	**SAB example measure**	**TEAP criterion**
	physical structure	tree canopy height	NONE
Species & populations	population size	density	NONE
	genetic diversity	degree of heterozygosity	NONE
	population structure	age structure	NONE
	population dynamics	dispersal rates	NONE
	habitat suitability	focal species requirements	Combination of GIS layers
Organism condition	physiological status	hormone levels	NONE
	symptoms of disease	tumors, lesions	NONE
	signs of disease	tissue burden of contaminants	TRI weighted air/water releases

CHEMICAL AND PHYSICAL CHARACTERISTICS

Nutrient concentrations	Nitrogen	concentration of N	water quality
	Phosphorus	concentration of total P	water quality
	other nutrients	concentration of Ca, K, Si	water quality
Trace inorganic & organic chemicals	metals	Cu, Zn in sediment	NONE
	trace elements	Se in water and soil	NONE
	organic compounds	methyl-Hg	NPL (Superfund) Sites
			RCRA corrective action sites

Category	Subcategory	SAB example measure	TEAP criterion
Chemical properties	pH	pH in water & soil	NONE
	dissolved O	DO in streams	water quality
	salinity	conductivity	NONE
	organic matter	soil organic matter	NONE
	other	buffering capacity	NONE
Physical parameters	soil/sediment	temperature, texture	soil permeability, aquifer/geology ranking
	air/water	concentration of particulates	air quality
			change in elevation
			airport noise
			temperature & precipitation maxima

HYDROLOGY & GEOMORPHOLOGY

Surface & groundwater flows	pattern of surface flow	water level fluctuations	watershed obstructions
			waterway impoundments
	hydrodynamics	water movement	NONE
	pattern of groundwater flows	depth to groundwater	NONE
	spatial salinity patterns	surface salinity gradients	NONE
	water storage	aquifer capacity	NONE
Dynamic structural characteristics	channel morphology complexity	length of natural shoreline	NONE
	dist. of connected floodplain	2yr or 10yr floods	NONE

Category	Subcategory	SAB example measure	TEAP criterion
	aquatic physical habitat	pool-riffle ratio	NONE
Sediment & material transport	sediment movement	sediment deposition	NONE
	particle size distribution	distribution of grain size	NONE

2. 0 METHODS

2.1 Base Unit Selection

Technical experts from TERS agencies discussed the relative merits of using ecoregions or watersheds as the base unit for the assessment. It is generally agreed that both watersheds and ecoregions provide "essential geographic frameworks necessary to describe, diagnose, and eventually, predict landscape influences on water resources" (Harrison et al. 2000). The TERS Steering Committee concluded that ecoregions have the following distinct advantages over watersheds for ecosystem management:

> An ecoregion approach provides a comprehensive review of an area's functionality in relationship to terrestrial habitat, aquatic habitat, and the species and communities they supported. Some species and communities depend upon a single large patch or several different kinds of habitat that span more than one watershed.
>
> Texas has over 200 watersheds. A watershed-based assessment would be time and resource intensive. Therefore, using watershed-based assessment would not be expedient enough to meet the initial needs identified by the TERS executives.
>
> Large watersheds, particularly basins, do not necessarily correspond to areas that contain a similarity in the mosaic of geographic characteristics which include, physiography, soils, vegetation, geology, climate, that influence the physical, chemical or biological nature of water bodies (Omernik 1995, Omernik and

> Bailey 1997). However, the quantity and quality of water tends to be similar within ecoregions (Griffith et al. 1999).

> Land cover and other spatial data are readily available by ecoregion to summarize and map numerous landscape features thought to be important to water quality concerns.

> Ecoregions are functional conservation areas that maintain focal species, communities, and/or systems, and support ecological processes within their natural ranges of variability (Poiani et al. 1998, Poiani and Richter 1999, Poiani et al. 2001).

TEAP used ecoregions, developed by Bailey (1985, 1987, 1994, 1996) because of extensive delineation of representative ecoregions and sub-regions within Texas and the use of plant community relationships (Bailey 1994) (Figure 1). There are eighteen ecoregions identified by Bailey in Texas. The characteristics of each are described in Appendix A. Bailey's ecoregions has broad usage by a number of agencies and organizations, including the USFS, USGS, FWS, EPA, and The Conservancy.

GIS data, particularly NLCD, used in specific calculations were summarized for each square kilometer (1km^2). Although NLCD has a 30 m^2 pixel resolution, performing calculations for a "1 km^2 grid" allowed maintenance of confidentiality of rare species occurrences, as well as reducing computer computation resources.

The NLCD classification contains twenty-one different land cover categories with a spatial resolution of 30 m. The NLCD was produced as a cooperative effort between USGS and EPA to produce a consistent, land cover data layer for the conterminous U.S. using early 1990s Landsat thematic mapper data purchased by the Multi-resolution Land Characterization (MRLC) Consortium. The MRLC Consortium is a partnership of federal agencies that produce or use land cover data. Partners include the USGS, EPA, USFS, and the National Oceanic and Atmospheric Administration (NOAA).

Several steps are used to process NLCD: 1) an automated process is used to create clusters of pixels for a given regional area, 2) these clusters are interpreted and labeled with the help of aerial photographs, 3) in cases where clusters of pixels include multiple land cover types, models that use data such as elevation or population density, are used to help assign land cover classes, and 4) lands that are bare and many grassy areas, such as parks and golf courses are not easily distinguished from other land cover classes, so on-screen verifications are used for clarification (Vogelmann et al. 1998, 2001).

The analysis and interpretation of the satellite imagery was conducted using very large, sometimes multi-state image mosaics (i.e. up to eighteen Landsat scenes). Using a relatively small number of aerial photographs for 'ground truth', the thematic interpretations were necessarily conducted from a spatially-broad perspective.

The accuracy of NLCD and satellite-derived data is related to many factors including the amount of data available, the detail of the required land cover information, classification methods, computing power, and time and money (H. John Heinz III Center for Science, Economics and the Environment 2002). Furthermore, the accuracy assessments are performed on groupings of contiguous states. Thus, the reliability of the data is greatest at the state or multi-state level. Assessments of the NLCD for the eastern U.S. indicate an accuracy of approximately 80% or higher for general land cover categories (e.g., forest, agriculture, developed) (H. John Heinz III Center for Science, Economics and the Environment 2002).

2.2 TEAP Sub-layers and Layers

Ultimately, the CrEAM (Mysz et al. 2000, White et al. 2003) was selected as a base method. Due to differences between Region 5, the Midwest U. S., and Texas, subsequent modifications were made (Table 3).

Data were provided by EPA, TPWD, TCEQ (Table 4) and The Conservancy (for the spatial accuracy assessment). Data were processed and analyzed by EPA Region 6, TPWD, and The Conservancy (spatial accuracy assessment). Several processing steps were needed to convert the data or coverages to the same scale. General descriptions of the layers and sub-layers can be found in the Introduction.

2.2.1 Diversity Layer

The overall diversity layer was calculated for each ecoregion by taking the mean of the four diversity sub-layers and rescaling on a 0-100 scale. The values of the 30 m pixels that made up each 1 km^2 grid cell were averaged to determine the Diversity Index score for each cell.

2.2.1.1 Appropriateness of Land Cover

TEAP reclassified the Potential Natural Vegetation (PNV) 2000 (Kuchler 1964) grid to the NLCD classification (Table 5). Reservoirs were also reclassified and grouped according to ecoregion because of their anthropogenic nature. The current NLCD was compared to the modified PNV 2000 data and values that were the same received a score of 10,000, representing

Table 3. Summary of TEAP layers.

Criterion	Indicator	Description	Data Source	Analysis Unit	Analysis Resolution	Pixel Scoring
Diversity	Shannon land cover diversity index	1. Shannon Diversity Index 2. Considers both richness (# of different specific land cover types) and evenness (dispersion of cover types) 3. Undeveloped land cover types only 4. Relative land cover diversity within ecoregions	NLCD, Bailey's ecoregions	ecoregion	1 km	continuum, exponential distribution
	Land cover appropriate-ness	1. Evaluation of land cover type currently present (c. 1993) relative to potential dominant vegetation native to the area as an appropriateness factor of measured diversity 2. Comparison of NLCD land cover and PNV	NLCD, PNV	Texas	30 m	0/1
	Contiguous size of undeveloped land	1. Selection of largest contiguous non-developed areas based on principle that larger non-developed areas favor diversity 2. All undeveloped cover types that are adjacent form one polygon	NLCD, Bailey's ecoregions	ecoregion	1 km	continuum, exponential distribution
*	Ecologically significant stream segments	1. Relates health of waterways relative to pristine conditions of water quality, habitat quality, and occurrence of health indicator aquatic species	TPWD	Texas	stream segments	0/1
**	Temperature and precipitation maxima	1. Based on assumption that higher temperatures and greater precipitation favors diversity		ecoregion	meteoro-logical bands	0/1

Criterion	Indicator	Description	Data Source	Analysis Unit	Analysis Resolution	Pixel Scoring
Rarity	Vegetation rarity	1. Determination of which land cover type is the rarest	NLCD	ecoregion	30 m	continuum, log distribution
	Natural heritage rank	1. G1, G2, G3, S1, S2, and S3 occurrences	BCD	7.5 minute quadrangle	point observations	continuum, exponential distribution
	Rare species richness	1. The number of species rated as G1-3 2. The number of observationss associated with each species	BCD	7.5 minute quadrangle	point observations	continuum, exponential distribution
	Taxonomic richness	1. The number of species rated as G1-3 2. The number of broad taxonomic groups represented	BCD	7.5 minute quadrangle	point observations	continuum, exponential distribution
Sustainability: Fragmentation	Contiguous land cover type	1. Selection of largest contiguous areas by specific land cover type 2. Based on the principle that larger areas having similar ecosystem types have greater sustainability 3. Each undeveloped land cover type is a separate polygon 4. Only polygons $\geq$10 ha considered	NLCD, Bailey ecoregions	ecoregion	30 m	continuum, exponential distribution
	Appropriate-ness of land cover	1. Comparison of NLCD land cover with PNV 2. Evaluation of land cover type currently present (c.1993) relative to potential dominant native vegetation as an indicator of resilience and the likelihood of sustainability (seed bank) of the corresponding ecosystems	NLCD, PNV	Texas	30 m	0/1

Criterion	Indicator	Description	Data Source	Analysis Unit	Analysis Resolution	Pixel Scoring
	Road density	1. Roads fragment the landscape 2. Road density index applied to TIGER road data set considers the total road lengths of different road classifications, classification of 1 km cells into road density ranges	TIGER	1 km cells	1 km	continuum, exponential distribution
	Regularity of ecosystem boundaries	1. Selection of contiguous areas possessing the smoothest or least irregular boundaries (i.e., lowest PAR by land cover) 2. Based on the principle that the least amount of boundary results in the lowest amount of "edge effect" thereby yielding the least disturbance or greatest sustainability of the interior ecosystems 3. Only polygons $\geq$10 ha considered	NLCD, Bailey's ecoregions	ecoregion	30 m	continuum, exponential distribution
	Waterway obstruction	1. Dam density per watershed (normalized by stream miles) 2. Dams and the corresponding reservoirs are interruptions (fragmentation) to the continuities of waterways	TCEQ, USGS	8-digit HUC	HUC	continuum, log distribution
**	Waterway impoundment	1. Selection of reservoirs for downgrading 2. Intersection of NLCD open water class and STORET dam locations	STORET	Region 5	30 m	0/-1

Criterion	Indicator	Description	Data Source	Analysis Unit	Analysis Resolution	Pixel Scoring
Sustainability: Stressors	Airport noise	1. The zone of disturbance surrounding airports are directly related to the sizes of the airplanes using them. 2. Airplane sizes are directly related to airport runway lengths. 3. The extent of the zone of disturbance is directly related to the runway length.	Bureau of Transportation Statistics runway length	airport	site or runway length w/ buffer	runway w/buffer
	NPL sites (Superfund) & state Superfund sites	1. Un-owned sites where hazardous waste was released to the environment and which were in the formal clean-up process	CERCLIS data, TCEQ	Texas	site w/buffer	0/1
	RCRA TSD, corrective action, and state VCP sites	1. Owned sites where hazardous waste was released to the environment and which were in the formal clean-up process	RCRIS data, TCEQ	Texas	facility w/buffer	0/1
*	Air quality	1. Nonattainment and state near nonattainment areas	EPA green book, TCEQ	county	county	0/0.5/1
	Urban/ agricultural disturbance	1. Activities in urban & agricultural areas generate disturbances to surrounding areas. 2. Takes into account stressors such as pesticides, fertilizers, and noise	NLCD	Texas	30 m	0/1

Criterion	Indicator	Description	Data Source	Analysis Unit	Analysis Resolution	Pixel Scoring
	Water quality	1. Ambient levels of total suspended solids, dissolved oxygen, and ammonia based on modeling of 1990-1994 NPDES permitted discharges levels 2. Status of water quality use support, including waters identified as impaired, with water quality concerns, or fully meeting uses 3. Only use support pertaining to aquatic life is included (includes depressed dissolved oxygen, pH extremes, ambient toxicity, elevated heavy metals, and nutrient or sediment quality concerns)	TCEQ CWA 303(d) list	Texas	stream	0/1

*addition/modification to CrEAM
**deletion from CrEAM

Table 4. GIS data layers used for the TEAP.

Criterion	Database	Description	Scale	Date	Agency
Diversity	NLCD	land use/land cover interpreted from satellite imagery	30 m	1990-1992	USGS
	PNV	PNV is the climax vegetation that will occupy a site without disturbance or climatic change. It is an expression of environmental factors such as topography, soils, and climate across an area.	PNV map was digitized for the coterminous US then adjusted to match terrain using a 500 m DEM, 4th code HUC, and Bailey ecological subregions	1964 (v. 2000)	USFS
	Bailey's ecoregions section map	ecosystem geography based on plant community relationships	1:7,500,000	1994	USFS
	ecological stream segments of concern	ecologically significant river/stream segments	1:200,000	2000-2001	TPWD
Sustainability	NLCD				
	Bailey's ecoregions				
	reservoirs/dams STORET	waterway impoundments			EPA
	TIGER road data				Census
	CERCLIS	NPL sites			EPA
	RCRIS	RCRA corrective action sites			EPA

Criterion	Database	Description	Scale	Date	Agency
	TMDLs	CWA 303(d) listed impaired waterbodies		1993-1998	TCEQ
	14-digit & 8-digit HUC	watersheds	1:1,000,000	2002	USGS, NRCS
	TRI	reported facility air emissions			EPA
Rarity	BCD	T&E elemental occurrences	7.5' quadrangle and county	1994	TPWD
	natural heritage	G/S species rankings	7.5' quadrangle and county	1994	TPWD
Other	conservation planning areas	aquatic and terrestrial areas capturing a range of rare and representative native plants, animals and natural communities			TNC

Table 5. Kuchler (1964) PNV classifications and corresponding NLCD land cover types.

PNV	Class. No.	NLCD	Class. No.
		Open water	11
		Perennial ice/snow	12
		Low intensity residential	21
		High intensity residential	22
		Commercial/Industrial/Transportation	23
		Bare rock/sand/clay	31
		Quarries/strip mines/gravel pits	32
		Transitional	33
Cross timbers	40	Deciduous forest	41
Oak-hickory	45	Deciduous forest	41
Pine-Douglas fir	3	Evergreen forest	42
Pine forest	1	Evergreen forest	42
Juniper-pinyon	22	Evergreen forest	42
Chaparral	26	Mixed forest	43
Oak-hickory-pine	55	Mixed forest	43
Southern mixed forest	56	Mixed forest	43
Southwest shrub steppe	27	Shrubland	51
Desert shrub	28	Shrubland	51
Shinnery	29	Shrubland	51
Texas savannah	35	Shrubland	51
		Orchards/vineyards/other	61
Plains grassland	32	Grasslands/Herbaceous	71
Prairie	33	Grasslands/Herbaceous	71
Desert grassland	34	Grasslands/Herbaceous	71
		Pasture/Hay	81

PNV	Class. No.	NLCD	Class. No.
		Row crops	82
		Small grains	83
		Fallow	84
		Urban/recreational grasses	85
Southern floodplain	61	Woody wetlands	91
Wet grassland	36	Emergent herbaceous wetlands	92
Reservoirs	63	Various; dependent on ecoregion	

no change from pre-settlement to modern times and those that were not the same received a score of zero, indicating disturbance due to human activities. The 0 to 10,000 values, based on thirty meter pixels, were then converted to a 0 to 250 scale and reclassified the resulting data onto an 8-bit grid. It was rescaled so that the data could be stored as 8-bit. Eight-bit data avoids computer memory and buffer overloads during processing and in no way affects the outcome, since the relative scores within the data set accurately reflect the content of the data. The final score is an average of all pixels in a 1 km^2.

Kuchler's PNV map was refined by USFS to match terrain using a 500 m Digital Elevation Model (DEM), 4th level Hydrologic Unit Codes (HUC), and Ecological Subregions (Bailey's Sections). These biophysical data layers were integrated with current vegetation layers to develop generalized successional pathway diagrams. Expert regional panels refined the PNV map based on these successional pathways. Summaries of the data were restricted to state or USFS regional scales.

2.2.1.2 Contiguous Size of Undeveloped Land

Using NLCD coverage and land cover classes, the data were classified as either developed or non-developed within each ecoregion. "Non-developed" classes are identified by the following land cover categories: 1) open water, 2) bare rock/sand/clay, 3) deciduous forest, 4) evergreen forest, 5) mixed forest, 6) shrubland, 7) grasslands/herbaceous, 8) woody wetlands, and 9) emergent herbaceous wetlands. All other classes are considered "developed."

For this measure in TEAP, adjacent undeveloped land cover types in each ecoregion are combined into one polygon, e.g., adjacent forest, wetlands, and grasslands are all one polygon. Thirty meter pixels of each land cover type were scored in each ecoregion. The size of the contiguous area in each Texas ecoregion was computed as was a linear index based on area using the following parameters: (1) contiguous areas < 10 hectares (ha) received a score of zero, indicating small areas of an undeveloped land cover type; and (2) contiguous areas > 100,000 ha, received a score of 250, indicating large areas of an undeveloped land cover type in each ecoregion. All other areas were ranked in the index by dividing the total contiguous area by 400. Rescaling was done so that the data could be stored as 8-bit data which avoids computer memory and buffer overloads during processing. Rescaling does not affect the outcome, since the relative scores within the data set accurately reflect the content of the data.

2.2.1.3 Shannon Land Cover Diversity Index

This calculation applies the Shannon-Weiner diversity index using the NLCD coverage to the relative land cover diversity within each ecoregion. The Shannon index is an established method used to measure ecological diversity (richness and evenness) (Begon et al. 1986). It usually calculates the proportion of individuals, but as used here, land cover types, related to the total number of land cover types. Other ecological diversity measures used in landscape assessment are discussed in Herzog et al. (2001). The Shannon-Wiener equation considers both richness (the quantity of different categories) and the evenness (the similarity of relative abundance).

The Shannon land cover diversity index for each ecoregion was calculated using the Analytical Tools Interface for Landscape Assessments Version 3.0 (ATtILA) (Harrison et al. 2000). Water land cover classes were removed in the GIS coverage used due to human-made reservoirs. Calculations were made by summarizing 30 m^2 pixels into a one kilometer grid. The results of the Shannon land cover diversity index calculations using ATtILA were normalized to a 1 to 250 scale so that the highest value in an ecoregion is equal to 250 and the lowest value is equal to one. The 1 to 250 scores were then used to populate the 1 km raster grid.

Reservoirs are considered “developed” due to the managed and many, characteristically “unnatural” attributes when compared to natural lakes. Differences in shoreline shape, nutrient balance, water temperature, drainage characteristics, salinity, plus the lack of or reduced seasonal flow fluctuation (though this may be simulated by controlled dam releases) contribute to lower biodiversity, and lower “ecological value” of this land cover type as compared to natural and non managed aquatic ecosystems.

2.2.1.4 Ecologically Significant Stream Segments

For this sub-layer, the initial data was reprojected from the Texas State Mapping System (TSMS) to TxAlbers map projection and attribute data was added to facilitate overlays with other coverages. The results were applied to the raster grid and all grid cells containing significant stream segments received a value of 10,000.

2.2.2 Rarity Layer

The overall rarity layer was calculated by taking the mean of the four rarity layer sub-layers and rescaling on a 0 to 100 scale. The values of the 30 m pixels that made up each 1 km^2 grid cell were averaged to determine the rarity score for each cell. Overall rarity was calculated by recoding rarity ranks using an exponential growth function 0 to 250 to produce a statewide land cover rarity data set. Data were scaled 0 to 250, due to machine processing of 8-bit data. Because the input data sets for Texas were large, rescaling the data from 1 to 250 (8-bit) allowed for much faster machine processing without any significant loss of granularity. Exponential scaling was chosen to give appropriate weight to rarer features. The statewide land cover rarity data set and the land cover rarity by ecoregion data set were input into an averaging model to compute the mean value of each grid cell for the combined data sets.

2.2.2.1 Vegetation Rarity

The land cover or vegetation rarity measure is derived from the NLCD and represents rarity of all natural (undeveloped) cover types including water and bare rock. The following cover types are represented in this data set: 1) open water, 2) bare rock/sand/clay, 3) deciduous forest, 4) evergreen forest, 5) mixed forest, 6) shrubland, 7) grasslands/herbaceous, 8) woody wetlands, and 9) emergent herbaceous wetlands. All developed (non-natural) cover types were recoded as no-data. Because some land cover types may be common at the ecoregion level but rare statewide (e.g. coastal wetlands), land cover rarity was assessed at both the ecoregional and statewide level, then combined to produce a final land cover rarity measure. This process avoids under-evaluation of many important and rare cover types. For example, wetlands are rare statewide, but may be locally common in an ecoregion. The results of the two analyses (ecoregion and state) were combined by averaging the values of the corresponding grid cells to obtain an “average score” reflecting both the ecoregional and state scales. Pixel counts were conducted for each of the ecoregions and each cover type was recoded to a rarity rank based on its frequency distribution. Land cover rarity ranks were then recoded using an exponential growth function of 0 to 250 scale. Rescaling was done so that the data could be stored as 8-bit. Eight-bit data avoids computer memory and buffer overloads during processing and in no way affects the outcome, since the relative scores within the data set accurately reflect the content of the data. A shape file containing ecoregions was overlain on the NLCD coverage and a frequency distribution of land cover type by ecoregion was tabulated. The highest number of occurrences of a land cover type was considered the most common and given a score of one. The smallest number of occurrences of a land cover type was considered the rarest, and it was given a score of 10,000. Vegetation rarity was averaged over 30 m pixels in each 1 km^2 grid cell.

2.2.2.2 Natural Heritage Rank

This measure is derived from the TPWD’s Biological Conservation Database (TXBCD). TXBCD, established in 1983, is TPWD’s most comprehensive source of information on rare, threatened, and endangered plants, animals, invertebrates, high quality natural communities, and other significant features. The TXBCD is continually updated, providing current or additional information on statewide status and locations of these unique elements of natural diversity. However, the data are not all-inclusive. There are gaps in coverage and species data due to the lack of access to land or data, and insufficient staff and resources to collect and process data on all rare and significant resources.

The TXBCD was developed by The Conservancy back in the early 1970's and was continually maintained and updated by The Conservancy until its central science function was established as the Association for Biodiversity Information (now NatureServe). The data set that TPWD maintains as TXBCD is operating on an expired license. The official node of the NatureServe network in Texas is the Texas Conservation Data Center (TxCDC) housed within The Conservancy. The TxCDC collaborates with and provides data to TPWD, but there is no data sharing agreement at this time. The TxCDC database (BIOTICS), is a geographically-based system that contains records on nearly 9,000 species and communities in Texas.

Natural heritage rank for TEAP is derived from TXBCD attributes of global rank, state rank, federal protection and state protection. Natural heritage rank for TEAP is an absolute rank based upon natural heritage ranking criteria; which is itself a measure of rarity. Very specific criteria are used to determine rarity both globally and statewide, which is reflected in the natural heritage ranking system.

The natural heritage rank sub-layer reflects the combination of the state and global rankings for rare species in the state. Those that have a combined G1 and S1 rank are the "most imperiled." Locations that support G1 or S1 species are by definition unique ecological areas. Any state or federal listed species gets a rank= 1. TEAP ranks of 2-10 were computed by combining the SRANK and GRANK into a single score, e.g. G1 + S2 = TEAP rank 3 etc.

Because the spatial accuracy of each TXBCD point ranged from 30m to 8km, initial attempts at producing a polygon data set reflecting the spatial and attribute accuracy of the TXBCD produced a complex series of "regions" where polygons overlapped. Each of the thousands of resulting regions had multiple values for the class attribute. Accordingly, a decision was made to compute rarity by USGS quadrangle (7.5 minute) by intersecting the

TXBCD points with the USGS quadrangle boundaries. To better reflect the spatial extent of actual TXBCD data, the resulting USGS quadrangle shapes (attributed for rarity) were then intersected with the buffers (based on the spatial accuracy attribute of each point) of the TXBCD points, thus eliminating areas of the quad sheets beyond the actual spatial limits of the buffered points

After Natural heritage rank was computed, its value was used to populate the “class” field for TXBCD point shape file. Each class was then selected iteratively and separate shape files were created for each class. A spatial select of each TXBCD class was then done by USGS quadrangle boundary using a USGS quadrangle boundary shape file. Each quadrangle was accordingly attributed with a single class attribute reflecting the highest class rank that occurred within it. A separate polygon file was then generated from the TXBCD point shape file corresponding to the documented spatial accuracy of each point using the "precision" field. Seconds precise points were buffered to 30 m, minutes precise to 1800 m, etc. This file was then used to clip out the 7.5 minute quadrangle polygons to create a polygon coverage reflecting the known spatial extent (spatial accuracy of the TXBCD points) attributed with the corresponding USGS quadrangle’s "class" attribute. Finally, the polygons were attributed for class rank using the process used for the TXBCD point data described above. The resulting attributed polygon shape file was then merged with the output from the clip process described above to produce a species rarity shape file.

2.2.2.3 Taxonomic Richness

The taxonomic richness measure, or the number of rare taxa per USGS quadrangle, is derived from the TXBCD. The TXBCD point data were filtered by the same method used for the rarity rank measure. The number of observations of discrete broad taxonomic groups was based on classifications by The Conservancy (bryophyte, pterodophyte, gymnosperm plant, dicot plant, monocot plant, lichen, platyhelminthe, uniramian arthropod, insect, chelicerate, crustacean, mollusk, fish, amphibian, reptile, bird, and mammal). Unique values for the attribute for taxa were summed for each quad in which an observation occurred. The unique number of taxa per grid cell was sorted using a max filter to preserve the highest possible number of taxa per grid cell then recoded 0 to 250.

2.2.2.4 Rare Species Richness

The rare species data set suffers from a lack of geographic coverage and up-to-date inventories for many species, but is the best data set available. The species richness measure, or the number of rare species per USGS quadrangle, is derived TXBCD. The TXBCD point data were filtered by the same method used for the rarity rank measure and further processed and computed similar to the taxonomic richness measure described above.

2.2.3 Sustainability Layer

2.2.3.1 Contiguous Land Cover Type

Sources used for this layer were the NLCD and Bailey's Ecoregion Sections. Only undeveloped land cover types over 10 ha (100,000 square meters) were scored. The land cover types that were identified as undeveloped were 1) open water, 2) bare rock/sand/clay, 3) deciduous forest, 4) evergreen forest, 5) mixed forest, 6) shrubland, 7) grasslands/herbaceous, 8) woody wetlands, and 9) emergent herbaceous wetlands. The bare rock/sand/clay class designation contains features such as natural rock exposures, beaches, and sandbars and does not include mines and quarries. Using the ArcGIS Spatial Analyst Extension, adjacent cells of the same land cover type were grouped together and then the total area was calculated for each region (contiguous cells of the same land cover type). The $\log_{10}$ of each area was calculated and then normalized to a 0 to 100 in each ecoregion by land cover type. The largest area of each land cover type within each ecoregion received a score of 100. The smallest area of each land cover type within each ecoregion received a score of one. Other areas were scored exponentially between 1-100. Developed lands and undeveloped lands under 10 ha received a score of zero.

2.2.3.2 Regularity of Ecosystem Boundary

Sources used for this layer were the NLCD and Bailey's Ecoregions. Only undeveloped land cover types over 10 ha were scored. The land cover types that were identified as undeveloped were 1) open water, 2) bare rock/sand/clay, 3) deciduous forest, 4) evergreen forest, 5) mixed forest, 6) shrubland, 7) grasslands/herbaceous, 8) woody wetlands, and 9) emergent herbaceous wetlands.

The optimum case would be a perfect circle where the PAR approaches or is equal to one. Therefore, PAR would be (2*pi*r)/(pir2) = 2/r. Since it is preferable to represent PAR as a relative measure, rather than in absolute units, PAR is represented as [ideal PAR / real PAR]. This ratio is always less than or equal to one. Using the ArcGIS Spatial Analyst Extension, adjacent cells of the same land cover type were grouped together and the area and perimeter were then calculated for each region (contiguous cells of the same land cover type). The values for each polygon region ranged from 1.0 to 0.0000001. This value was then normalized to a 0 to 100 in each ecoregion by land cover type. With the exception of open water cells, the largest value of each land cover type within each ecoregion received a score of 100. The smallest value of each land cover type within each ecoregion received a score of one. Other values were scored exponentially between 1 to 100. For open water, the smallest value received the score of 100 and the largest value received the score of zero. Developed lands and undeveloped lands under 10 ha received a score of zero. A score of 100 means that the polygon is nearly a circle and a score of one is the most irregular polygon in the layer. This was done for each land cover type. For open water, irregular shorelines were deemed as being more ecologically important and received a score of 100. The open water portion of these reservoirs was scored zero to account for the reduced ecological value of open water as compared to the shoreline habitat.

2.2.3.3 Appropriateness of Land Cover

Appropriateness of land cover is calculated as described in the diversity section. TEAP reclassified the PNV 2000 (Kuchler 1964) grid to the NLCD classification (Table 5). Reservoirs were also reclassified and grouped according to ecoregion because of their anthropogenic nature. The current NLCD data was compared to the modified PNV 2000 data and values that were the same received a score of 10,000 representing no change from pre-settlement to modern times and those that were not the same received a score of zero, indicating disturbance due to human activities. The 0 to 10,000 values, based on thirty meter pixels, were then converted to a 0 to 250 scale and reclassified the resulting data onto an 8-bit grid. Rescaling was done so that the data could be stored as 8-bit. Eight-bit data avoids computer memory and buffer overloads during processing and in no way affects the outcome, since the relative scores within the data set accurately reflect the content of the data. The final score is an average of all pixels in a 1 km^2.

2.2.3.4 Waterway Obstruction

Sources used for this layer were data on dams from TCEQ, the National Hydrography Dataset (NHD) and 4th level (8-digit) HUCs from the USGS. This is the most refined level of hydrologic data that covers the entire state and is the best available data for the State of Texas. For each HUC in the state, the number of dams and the total length in miles of all streams and rivers was calculated. The number of dams was then divided by the stream miles to calculate dams per stream mile. This number was then normalized from 1 to 100 for each ecoregion. Those hydrologic units without dams received a score of 100 and the hydrologic unit in each ecoregion with the highest number of dams per stream mile received a score of one.

2.2.3.5 Road Density

Sources used for this layer was the 2000 Topological Integrated Geographic Encoding and Referencing System (TIGER)/line files from the U.S. Bureau of the Census. For each 1 km^2 cell the number of road miles by road classification was calculated. The road miles were then modified by multiplying the road miles with a factor based on the road classification. The following factors were applied to each road type:

TIGER Code	Classification	Factor
A0-A9	Miscellaneous Roads	1
A10-A29	Primary Roads	3
A30-A39	Secondary Roads	2.67
A40-A49	Local & Rural Roads	2
A50-A79	Miscellaneous Roads	1

After multiplying the road length by the road factor above, the totals for each classification were summed for each 1 km^2 cell. The $\log_{10}$ was then calculated for each cell. These were then normalized to 0 to 100. Cells having no roads would indicate no fragmentation and would be the ideal condition. These cells were given a score of 100. Cells having the highest density of roads were scored zero. Road density was calculated using the following formula:

$$(R*F)\ i\text{-}v = L$$

$$S = \{1- [\log_{10} (L) / 5.919]\}*100$$

where
R = the total road length of a classification code type within a grid cell
F = the loading factor for a classification code type
i-v = the five classification code types
L = the total loaded road length for a grid cell
S = the inverse loaded road length for a grid cell, i.e., road score
5.919 = $\log_{10}$ [road length*F]

A road score of 100 indicates an absence of roads and represents the ideal condition for self-sustainability.

The factors were derived from Sutherland (1994). In this document, the conclusion is made that disturbance effects may extend 500 to 600 m from quiet rural roads to 1600 to 1800 m from busy highways. Therefore, a factor of three presumably exists between the zones of disturbance generated by the smallest, least used roads and large, interstate highways. Local and rural roads are presumed to be intermediate generators of disturbance (thereby receiving a factor of two), whereas secondary roads, which include U.S. highways and state roads, are presumed to create disturbance regimes more similar to primary roads than to local and rural roads, thereby receiving a factor of 2.67. Since a road score of 100, indicates the complete absence of any roads, it represents ideal road presence for ecological self-sustainability.

2.2.3.6 Airport Noise

All runways were buffered, representing a zone of minimum disturbance around the airport based on runway size (Sutherland 1994). The buffer distances used were selected because the size of the zone of disturbance surrounding an airport is proportional to the size of the aircraft using it. Airplane size is directly related to the length of the runway. Therefore, the extent of the area of disturbance around an airport is related to runway length. The buffer zone is proportional to the runway length and each runway was grouped as follows (White et al. 2003):

Airport Category	Buffer (m)	=	Runway Length (m)
very large	7500		> 1950
large	5300		1500-1800
medium	3100		1200-1500
small	900		540-1200
very small	755		183-540
very very small	610		≤ 183

All areas in the state within the buffer were scored zero and areas outside the buffer were scored 100. This layer was then converted to a grid with a cell size of 1 km^2.

2.2.3.7 Superfund NPL and State Superfund Sites

Sources used for this layer include the NPL sites (in polygon and point format) from EPA and state Superfund Sites from TCEQ (in point format). For sites where polygon data was available, the polygon data was used. Otherwise a buffer of 610 m was used as a default (Sutherland 1994) and applied to the points. All areas in the state within a buffer were scored zero and areas outside of the buffer were scored 100. This layer was then converted to a grid with a cell size of 1 km^2. These are un-owned sites where hazardous waste was released and where there was a formal clean up process during fiscal year 2000.

2.2.3.8 Water Quality

This includes waters identified as impaired with water quality concerns or meeting designated uses in CWA Section 303(d). Only designated use data pertaining to aquatic life is included (e. g., dissolved oxygen, pH extremes, ambient toxicity, elevated heavy metals, nutrient or sediment levels in excess of the statewide 85^{th} percentile). The CWA 303(d) year 2000 list is an assessment of water quality data collected during 1993-1998 by TCEQ. The impaired waters layer was intersected with the 1 km^2 cell grid. Cells with impaired waters were scored zero and all others cells were given a score of 100.

2.2.3.9 Air Quality

The Air Quality layer characterizes areas with poor air quality. The source for this layer is ozone nonattainment from EPA's Office of Air Quality Planning and Standards (OAQPS) and

TCEQ. All the counties in Texas were scored from 0 to100 based on their nonattainment status. Counties that are in attainment were scored 100 and counties that are in severe nonattainment status were scored zero. The scores were assigned as follows:

Attainment Status	Normalized Score
Severe Nonattainment	0
Serious Nonattainment	25
Moderate Nonattainment	50
Near Nonattainment	75
Attainment	100

2.2.3.10 RCRA TSD, Corrective Action and State VCP Sites

Data sources used for this layer include RCRA corrective action sites (in point format) from EPA, RCRA TSD sites (in polygon and point format) from EPA and state Superfund Sites from TCEQ (in point format). For sites where polygon data was available, the polygon data was used otherwise a buffer of 610 m was used as a default (Sutherland 1994) and applied to the points. All areas in the state within a buffer were scored zero and areas outside of the buffer were scored 100. This layer was then converted to a grid with a cell size of 1 km^2. These are sites where hazardous waste was released and where there is a formal clean up process during fiscal year 2000.

2.2.3.11 Urban/Agriculture Disturbance

Sources used for this layer were land cover types from the NLCD. Only urban/ agricultural regions over 10 ha were included. A buffer of 600 m was included around the urban/agriculture areas to represent disturbance to surrounding areas. This is a minimum buffer size based on differences in road size and traffic in these developed land cover types (Sutherland 1994). The land cover types that were identified as urban and agricultural were low intensity residential, high intensity residential, commercial/ industrial/transportation, orchards/vineyards, pasture/hay, row crops, small grains, fallow, and urban/recreational grasses in NLCD. Using the ArcGIS Spatial Analyst Extension, the land cover types in the NLCD were reclassified to urban/agriculture or non-urban/agriculture. Adjacent cells of the same type were then grouped together and the area was calculated for each region (contiguous cells of the same land cover type). Urban/agricultural areas that were smaller than 10 ha were reclassified to non-urban/agriculture. A buffer of 610 m was then created around the urban/agriculture areas. All areas that are in urban/agriculture or within 610 m of urban/agriculture received a score of zero. All other areas were assigned a score of 100. This is a binary sub-layer, with scores for either developed land cover types (urban and agriculture) scoring zero and all natural land cover types scoring 100.

2.2.4 Accuracy Assessment

The Conservancy ecoregion portfolios for the Edwards Plateau, Southern Shortgrass Prairie, Chihuahuan Desert, Upper West Gulf Coastal Plain, West Gulf Coastal Plain, and Gulf Coast Prairies and Marshes were combined into a single GIS coverage. Of these portfolios, which consist of both aquatic and terrestrial conservation areas, only aquatic portfolio areas rated as Tier I (strong confidence that viable target populations and/or high quality system occurrences are present) within the Edwards Plateau and Southern Shortgrass Prairie were used since Tier II portfolio sites have a lower conservation value primarily due to lack of ground-truthing.

The single Conservancy portfolio coverage was then converted into a grid matching the TEAP composite grid layer specifications. To ensure a similar area of comparison, the TEAP composite grid was clipped to mask out data for the ecoregions not yet completed by The Conservancy (Tamaulipan Thornscrub and Crosstimbers and Southern Tallgrass Prairie). However, it should be noted that small areas of these two ecoregions were included where adjacent ecoregion conservation areas crossed ecoregion boundaries.

To reduce noise within the data, The Conservancy classified the data into thirty equal classes. Each class contained ten pixel values; for example class 1 equals TEAP composite values 1 to10, class 2 equals TEAP composite values 11 to 20, and so on.

All the data processing was performed utilizing ArcGIS 8.3 (ESRI Inc., Redlands, CA 2001). The individual TEAP files were imported as ESRI GRID (raster) files and merged to create four statewide grids representing Rarity, Sustainability, Diversity, and Composite. The resulting grids were 1,183 rows by 1,245 columns with each pixel representing 1 km^2.

The intersect between the TEAP composite layer and The Conservancy portfolio grids was calculated using the raster calculator function in ArcGIS. The result was two statewide grids, one for inside and one for outside The Conservancy combined portfolio. Summary statistics generated for each grid layer (e.g., mean, standard deviation, count, minimum, maximum, and sum). A frequency table of the TEAP composite pixel values was calculated and used to compare the frequency of pixel values found inside The Conservancy portfolio versus those found outside the portfolio. An additional map focusing on the IH69 corridor study site was created by clipping these three data sets to the IH69 corridor extent and recalculating the summary statistics to generate a new frequency table.

3.0 RESULTS

The composite map and underlying three layers are designed to assess the State of Texas by ecoregion and to identify the optimum ecological areas for protection and mitigation based on ecological theory (i.e., no political boundaries or regulatory programs). For presentation purposes, this report identifies "ecological importance" as percentages of the total score (theoretical maximum of 300) a grid cell can receive. Figures depicting the individual sub-layer data for the entire state can be found in Appendix B.

3.1 Diversity Layer

The diversity layer was designed to show land cover continuity and diversity in Texas (Figure 5). The statewide depiction shows a number of locations that scored in the top 1% per ecoregion. The individual sub-layer maps can be found in Appendix B. The diversity layer consists of four sub-layers: (1) appropriateness of land cover (Figure B1), (2) contiguous size of undeveloped land (Figure B2), (3) Shannon land cover diversity index (Figure B3), and (4) significant stream segments (Figure B4).

3.2 Rarity Layer

The rarity layer was designed to show rarity of species and land cover in Texas (Figure 6). The individual sub-layer maps can be found in Appendix B. The rarity layer consists of four sub-layers: (1) vegetation rarity (Figure B5), (2) natural heritage rank (Figure B6), (3) taxonomic

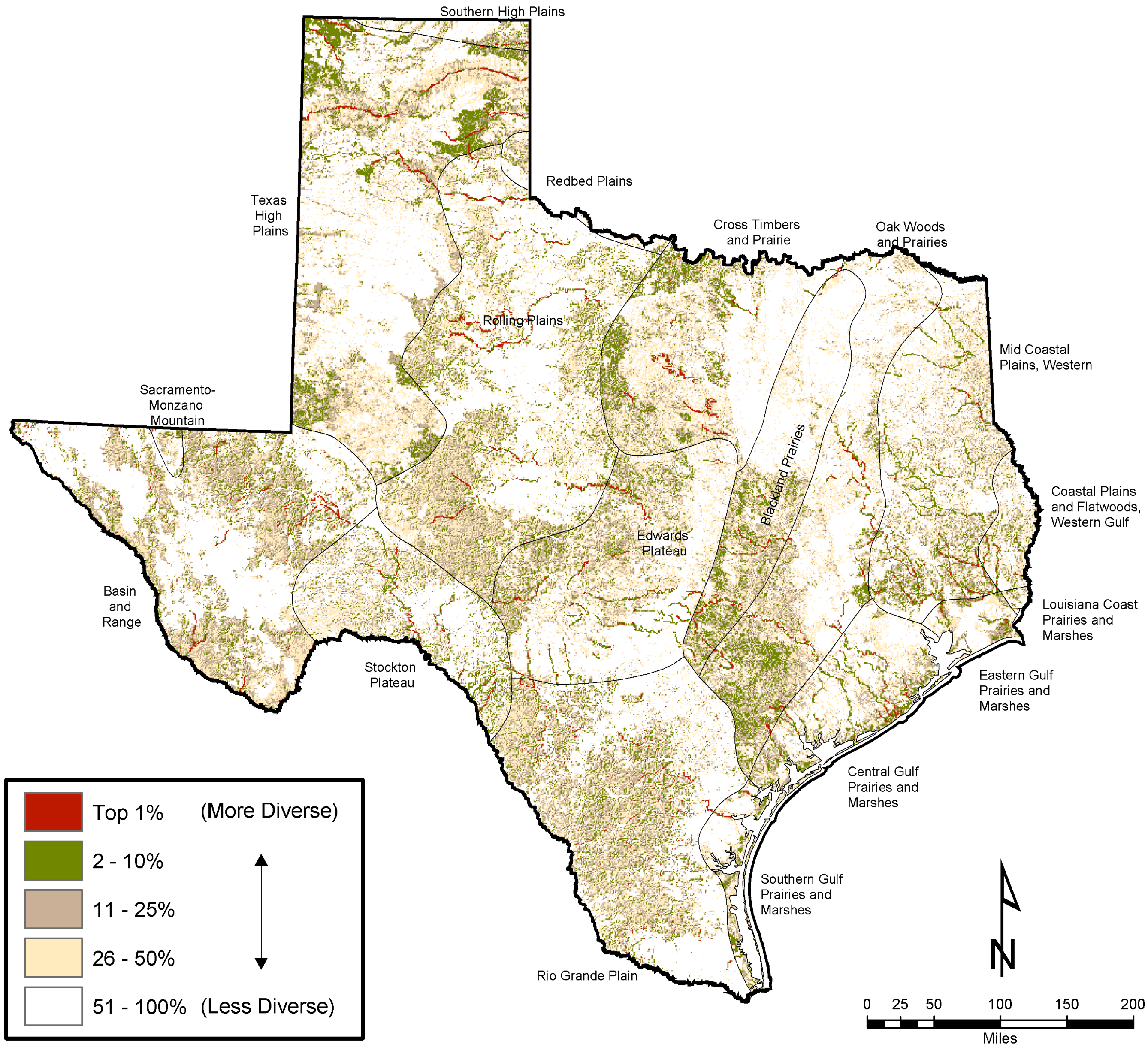

Figure 5. Map of the diversity layer with ecoregion boundaries. This map is a composite of four sub-layers (Figures B1-B4). Even though this map shows the entire state of Texas, the measures included in the diversity layer and subsequent composite maps (Figures 8-26) were calculated for each ecoregion.

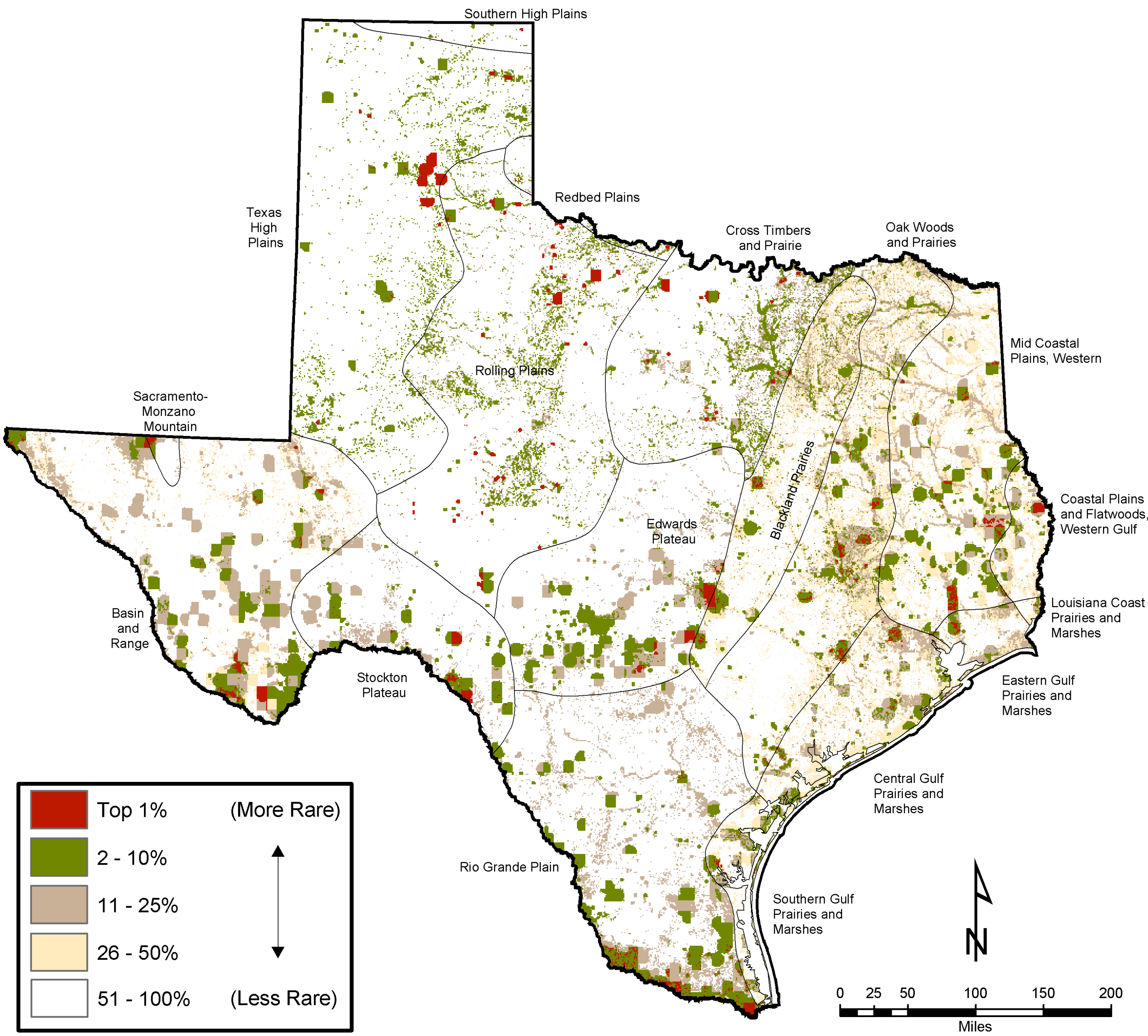

Figure 6. Map of the rarity layer with ecoregion boundaries. This map is a composite of four sub-layers (Figures B5-B8). Even though this map shows the entire state of Texas, the measures included in the rarity layer and subsequent composite maps (Figures 8-26) were calculated for each ecoregion.

richness (Figure B7), and (4) rare species richness (Figure B8).

The overall rarity map shows large areas of high rarity in the Stockton Plateau, Edward's Plateau Chihuahuan Desert Basin and Range, Mid Coastal Plains Western Section, and the southern portion of the Rio Grande Plain (Figure 6).

3.3 Sustainability Layer

The sustainability layer (Figure 7) consists of eleven sub-layers that can be loosely grouped into fragmentors: (1) contiguous land cover type (Figure B9), (2) regularity of ecosystem boundary (Figure B10), (3) appropriateness of land cover (Figure B11), (4) waterway obstruction (Figure B12), and (5) road density (Figure B13) and stressors: (1) airport noise (Figure B14), (2) Superfund NPL and state Superfund Sites (Figure B15), (3) water quality (Figure B16), (4) air quality (Figure B17),(5) RCRA TSD, corrective action and State VCP Sites (Figure B18), and (6) urban/agricultural disturbance (Figure B19). The individual sub-layer maps can be found in Appendix B. The more sustainable areas occur where there are fewer human disturbance activities.

3.4 Composite Layer

The composite map is the combination of the diversity, rarity, and sustainability layers (Figure 8). The top 1% highly important ecological areas in each ecoregion in Texas are highlighted in red. Most of the highly important ecological areas (1%, 10%) are those areas that

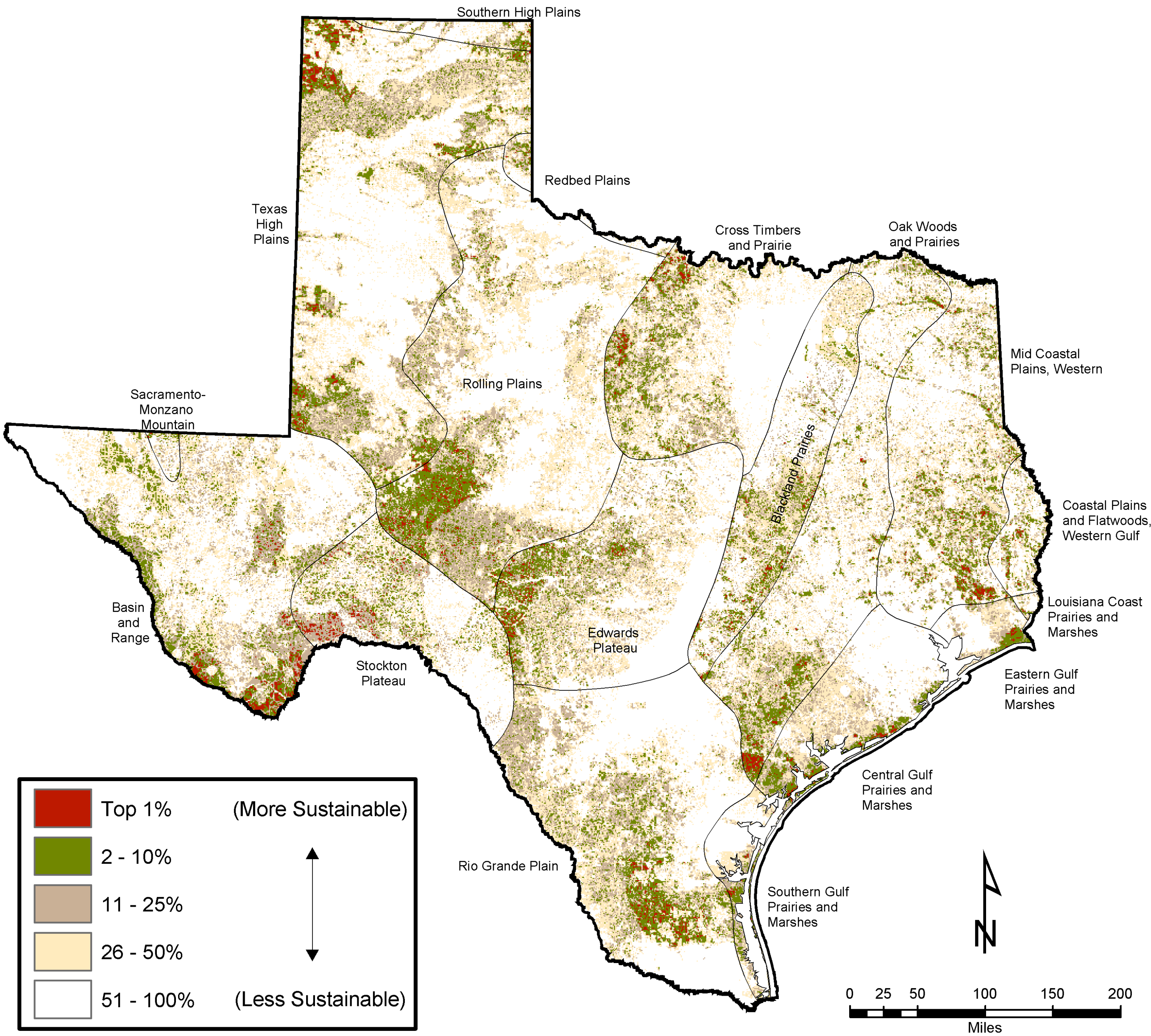

Figure 7. Map of the sustainability layer with ecoregion boundaries. This map is a composite of eleven sub-layers (Figures B9-B19). Even though this map shows the entire state of Texas, the measures included in the sustainability layer and subsequent composite maps (Figures 8-26) were calculated for each ecoregion.

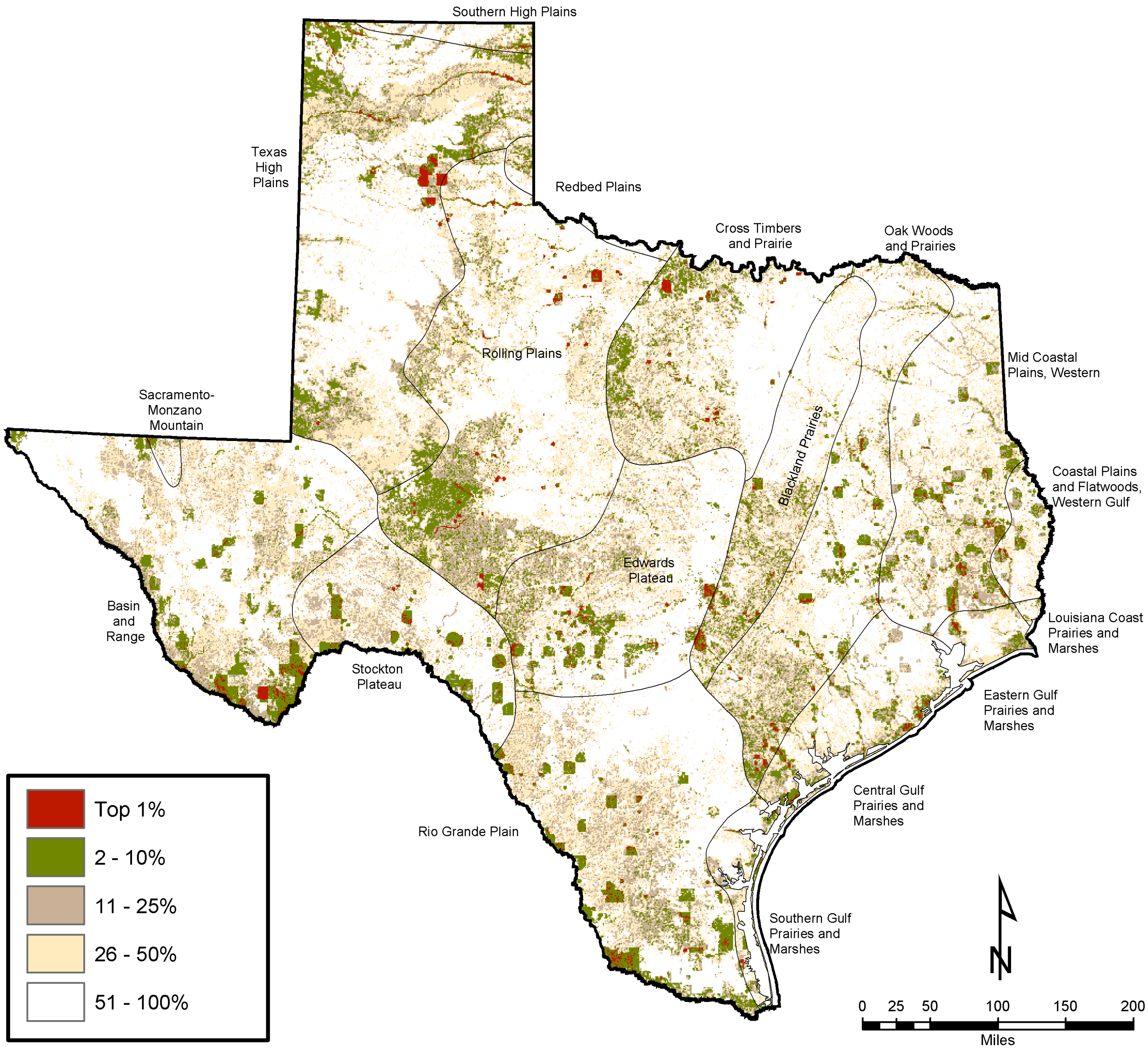

Figure 8. Composite map with ecoregion boundaries. This map is a composite of the diversity layer (Figure 5), rarity layer (Figure 6), and sustainability layer (Figure 7). Even though this map shows the entire state of Texas, the measures included in this map were calculated for each ecoregion. Individual sub-layer maps for each of the three main layers can be found in Appendix B. Those areas identified in red as the top 1% represent higher ecological importance, those identified in white as 51-100% represent lower ecological importance.

represent the intersection of the top 1% for diversity, rarity, and sustainability. Ecoregion results (Figures 9-26) are explained in the following section.

3.4.1 Ecoregion Composites

Descriptions of each of the ecoregions analyzed as well as representative photos appear in Appendix A. The following paragraphs contain brief summaries of the TEAP results by ecoregion.

3.4.1.1 Southern High Plains

The Southern High Plains is represented by a thin section on the north edge of the Texas panhandle. Most of the ecologically important areas (e.g., 1%, 10%, 25%) occur in the eastern portion of this ecoregion (Figure 9).

3.4.1.2 Texas High Plains

The Texas High Plains ecoregion shows several areas with high ecological importance. For example, the Canadian River is highlighted at the 1% and 10% levels as well as a larger riparian buffer at the 25% level. The northwest corner and an area southeast of the Canadian River are also highlighted and may have a high degree of rarity (Figure 10).

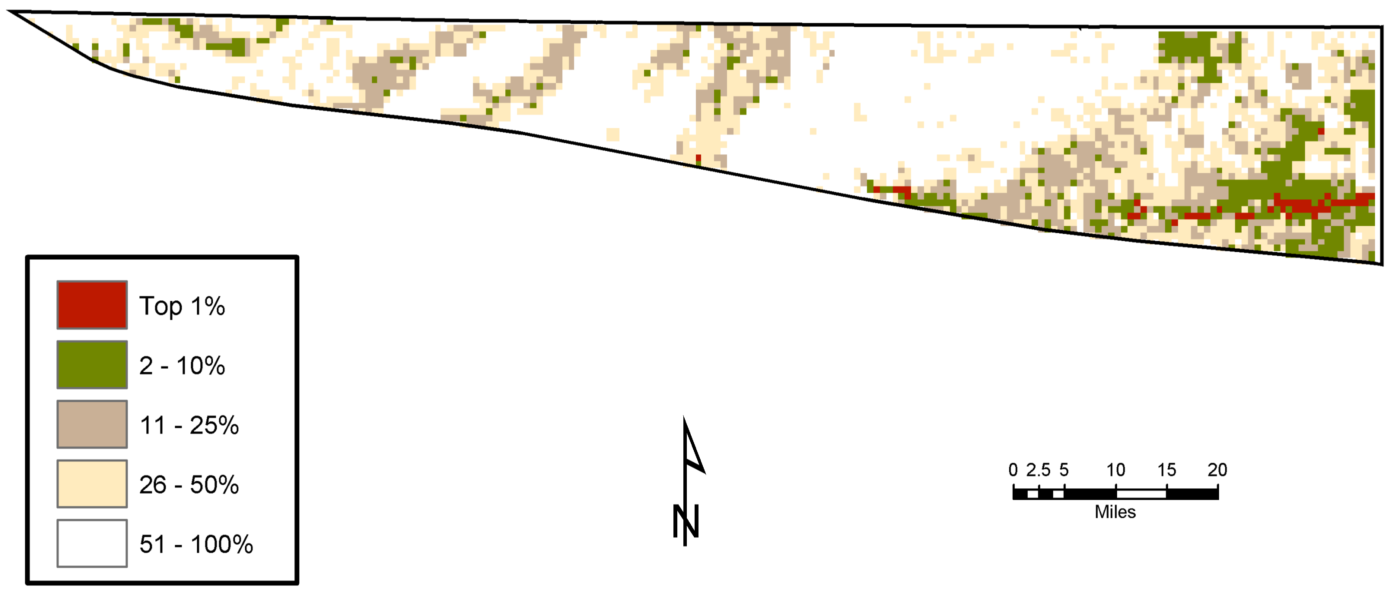

Figure 9. Southern High Plains composite map. A separate figure ([Figure 8]) shows the entire state. Those areas identified in red as the top 1% represent higher ecological importance, those identified in white as 51-100% represent lower ecological importance.

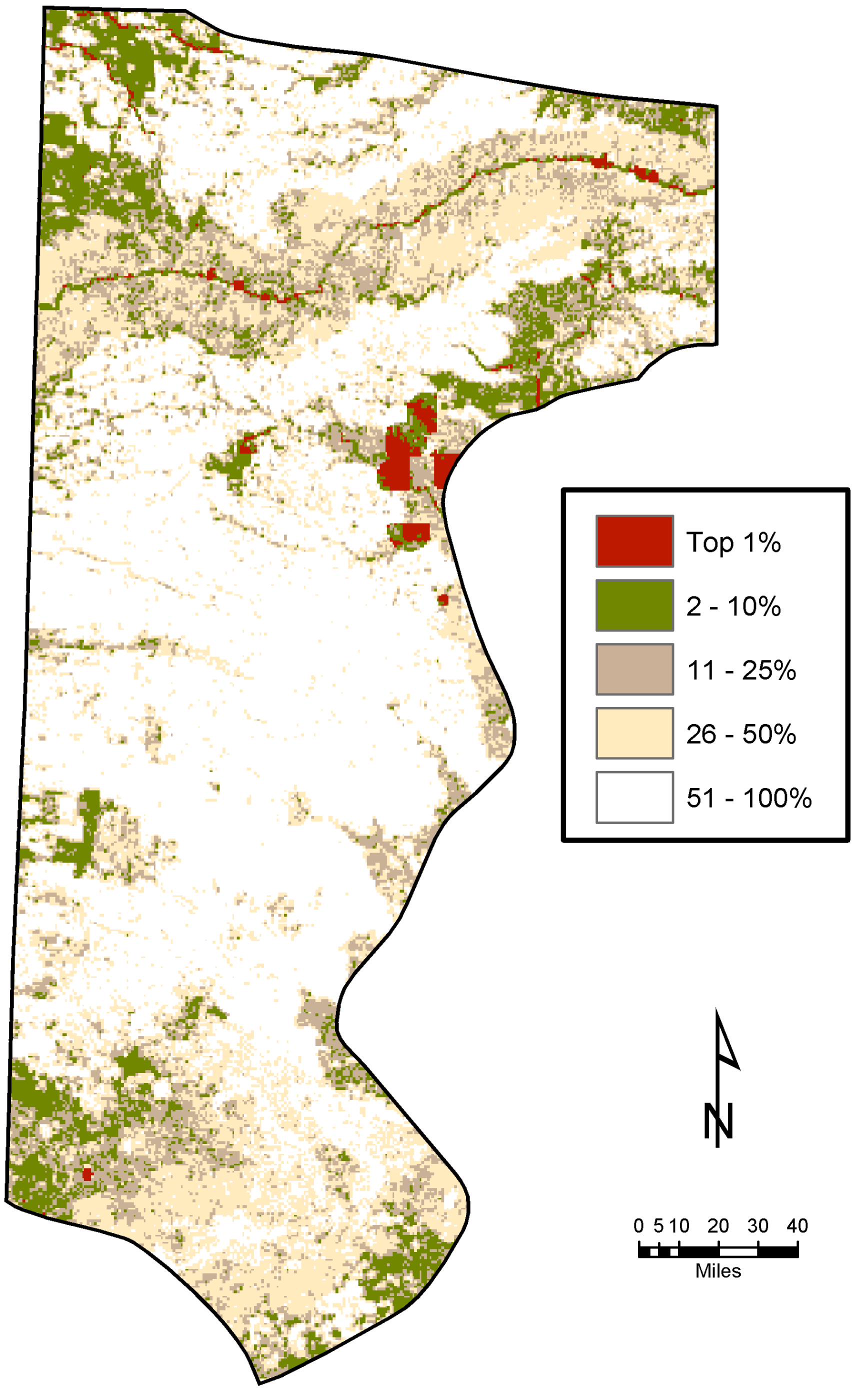

Figure 10. Texas High Plains composite map. A separate figure (Figure 8) shows the entire state. Those areas identified in red as the top 1% represent higher ecological importance, those identified in white as 51-100% represent lower ecological importance.

3.4.1.3 Rolling Plains

The southern portion of the Rolling Plains ecoregion shows a high level of ecologically important areas (Figure 11). Other areas representing the top 1% ecologically important areas are scattered throughout the ecoregion and may indicate locations of high rarity.

3.4.1.4 Rio Grande Plain

The Rio Grande Plain ecoregion contains areas of high levels of ecological importance throughout, although the northeastern portion of the ecoregion contains areas of lower importance (Figure 12). Relatively large ecological diversity and sustainable areas can be noted at the 10% level in this ecoregion.

3.4.1.5 Redbed Plains

The Redbed Plains is a very small, disjunct ecoregion in Texas, but extends into Oklahoma. Most of the ecologically important areas occur in the western portion of this ecoregion in Texas (Figure 13).

3.4.1.6 Cross Timbers and Prairie

The Cross Timbers and Prairies ecoregion shows ecological areas in the top 1% and 10% levels in the western half of the ecoregion (Figure 14). Several important riparian areas are noted.

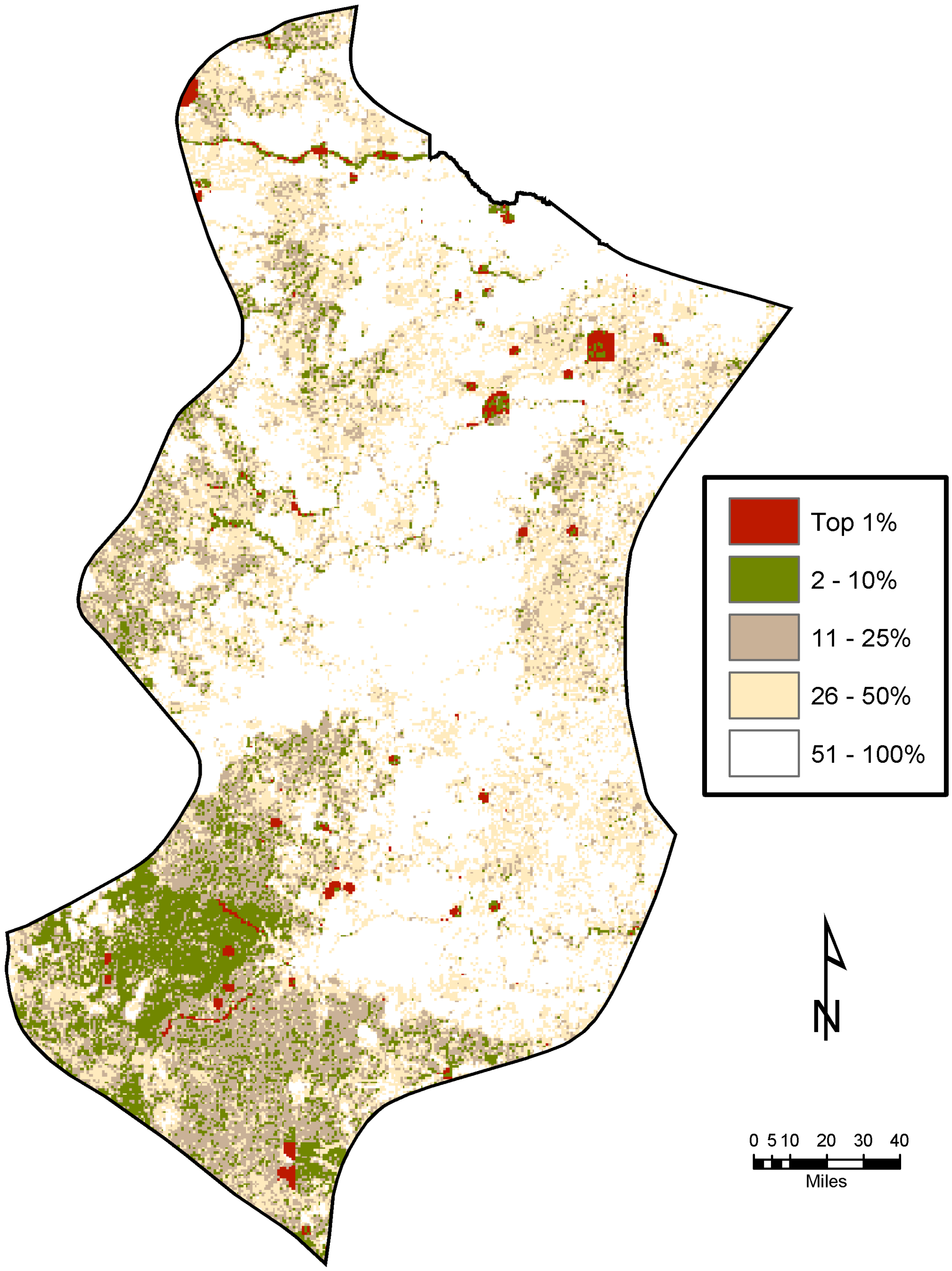

Figure 11. Rolling Plains composite map. A separate figure (Figure 8) shows the entire state. Those areas identified in red as the top 1% represent higher ecological importance, those identified in white as 51-100% represent lower ecological importance.

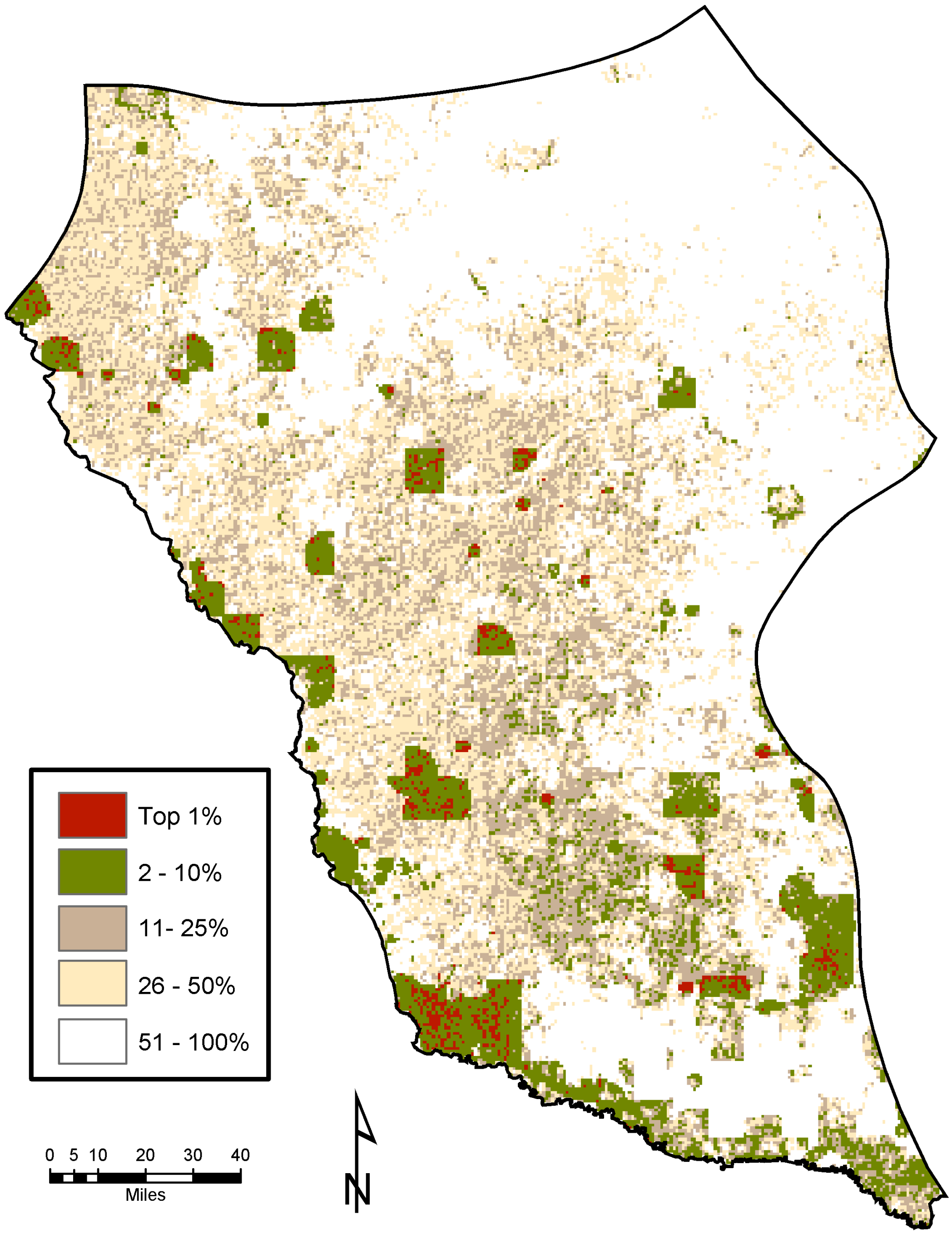

Figure 12. Rio Grande Plain composite map. A separate figure (Figure 8) shows the entire state. Those areas identified in red as the top 1% represent higher ecological importance, those identified in white as 51-100% represent lower ecological importance.

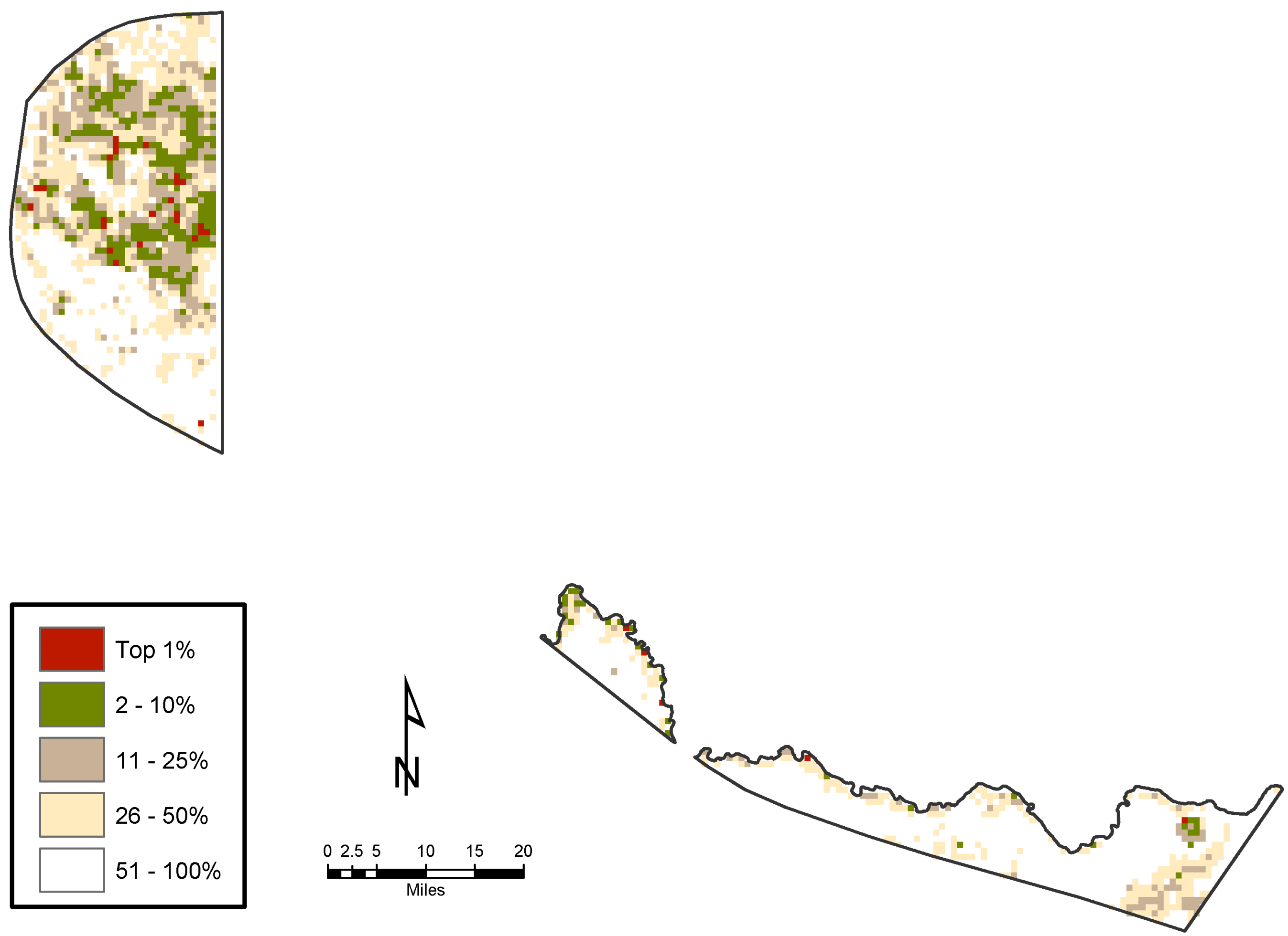

Figure 13. Redbed Plains composite map. A separate figure (Figure 8) shows the entire state. Those areas identified in red as the top 1% represent higher ecological importance, those identified in white as 51-100% represent lower ecological importance.

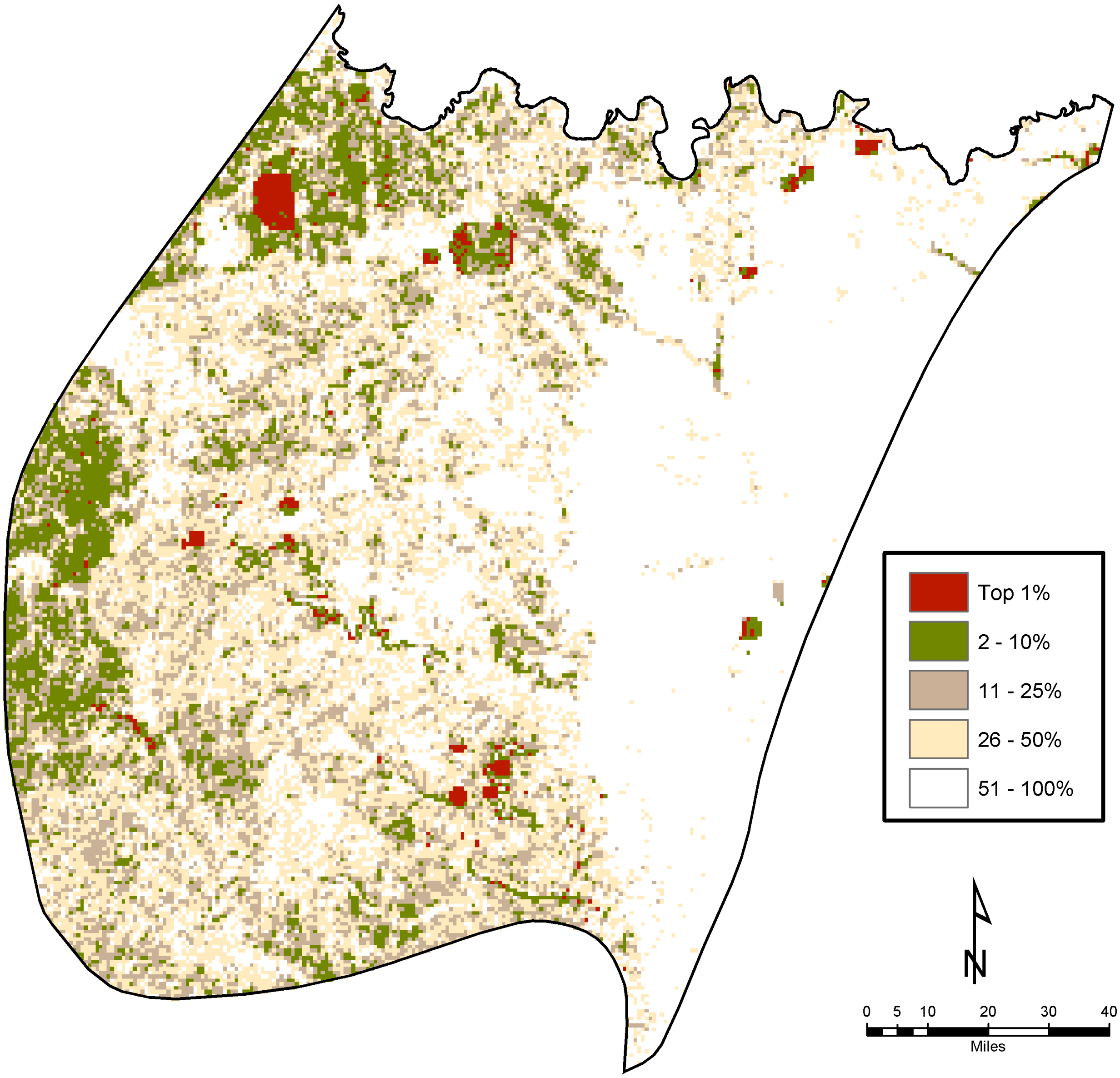

Figure 14. Cross Timbers and Prairie composite map. A separate figure (Figure 8) shows the entire state. Those areas identified in red as the top 1% represent higher ecological importance, those identified in white as 51-100% represent lower ecological importance.

3.4.1.7 Oak Woods and Prairies

There are ecologically important locations scattered throughout the Oak Woods and Prairies Ecoregion (Figure 15). The northern portion of this ecoregion may include the outskirts of large population centers such as Fort Worth. Several riparian corridors within this ecoregion are highlighted.

3.4.1.8 Blackland Prairie

The Blackland Prairie ecoregion may be one of the least sustainable ecoregions because of the large population centers, such as Dallas, located there; and the amount of ongoing agricultural activities. There seems to be a noticeable difference between the northern portion and the southern portion of this ecoregion (Figure 16). The southern portion shows much higher levels of ecologically important areas, including noticeable riparian areas.

3.4.1.9 Mid Coastal Plains Western Section

Traditionally called the “pineywoods”, the Mid Coastal Plains Western Section contains many areas of high ecological importance (Figure 17). Primarily in the southern portion of this ecoregion, several areas of high rarity and riparian areas are highlighted.

3.4.1.10 Coastal Plains and Flatwoods Western Gulf Section

Like the Mid Coastal Plains ecoregion, the Coastal Plains and Flatwoods Western Gulf Section ecoregion shows several areas of ecologically importance, primarily related to a high

Figure 15. Oak Woods and Prairies composite map. A separate figure (Figure 8) shows the entire state. Those areas identified in red as the top 1% represent higher ecological importance, those identified in white as 51-100% represent lower ecological importance.

Figure 16. Blackland Prairie composite map. A separate figure (Figure 8) shows the entire state. Those areas identified in red as the top 1% represent higher ecological importance, those identified in white as 51-100% represent lower ecological importance.

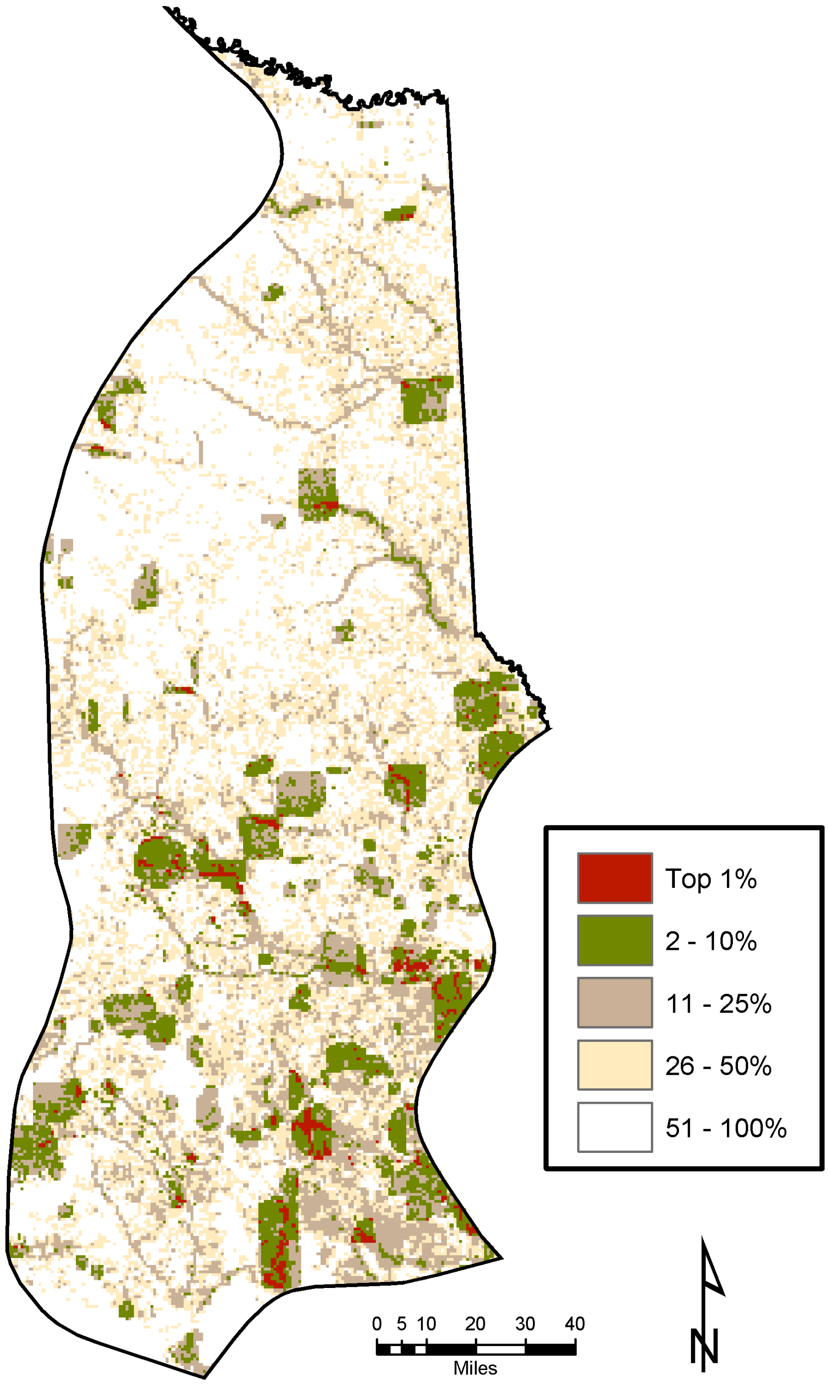

Figure 17. Mid Coastal Plains Western Section composite map. A separate figure (Figure 8) shows the entire state. Those areas identified in red as the top 1% represent higher ecological importance, those identified in white as 51-100% represent lower ecological importance.

degree of rarity throughout the ecoregion (Figure 18).

3.4.1.11 Edwards Plateau

The Edwards Plateau ecoregion has been studied extensively and is noted for its ecological importance, especially in terms of rare, endemic biota. The results of the TEAP indicate several relatively large areas in the south and southwest portions of the ecoregion due to the high degree of rarity (Figure 19). The northeastern portion of this ecoregion has primarily lower diversity, rarity, and sustainability. This area also includes the metropolitan center of Austin.

3.4.1.12 Stockton Plateau

The Stockton Plateau contains several relatively large areas of highly important ecological locations scattered throughout the ecoregion (Figure 20). These areas have a high level of rarity as well as diversity.

3.4.1.13 Chihuahuan Desert Basin and Range

The Chihuahuan Basin and Range ecoregion is a fairly large ecoregion in West Texas. Ecologically important areas at the 1%, 10% and 25% levels are scattered throughout the ecoregion. A relatively large ecologically important area is located in the southern portion of this ecoregion, representing a high degree of land cover diversity, rarity, and sustainablility (Figure 21).

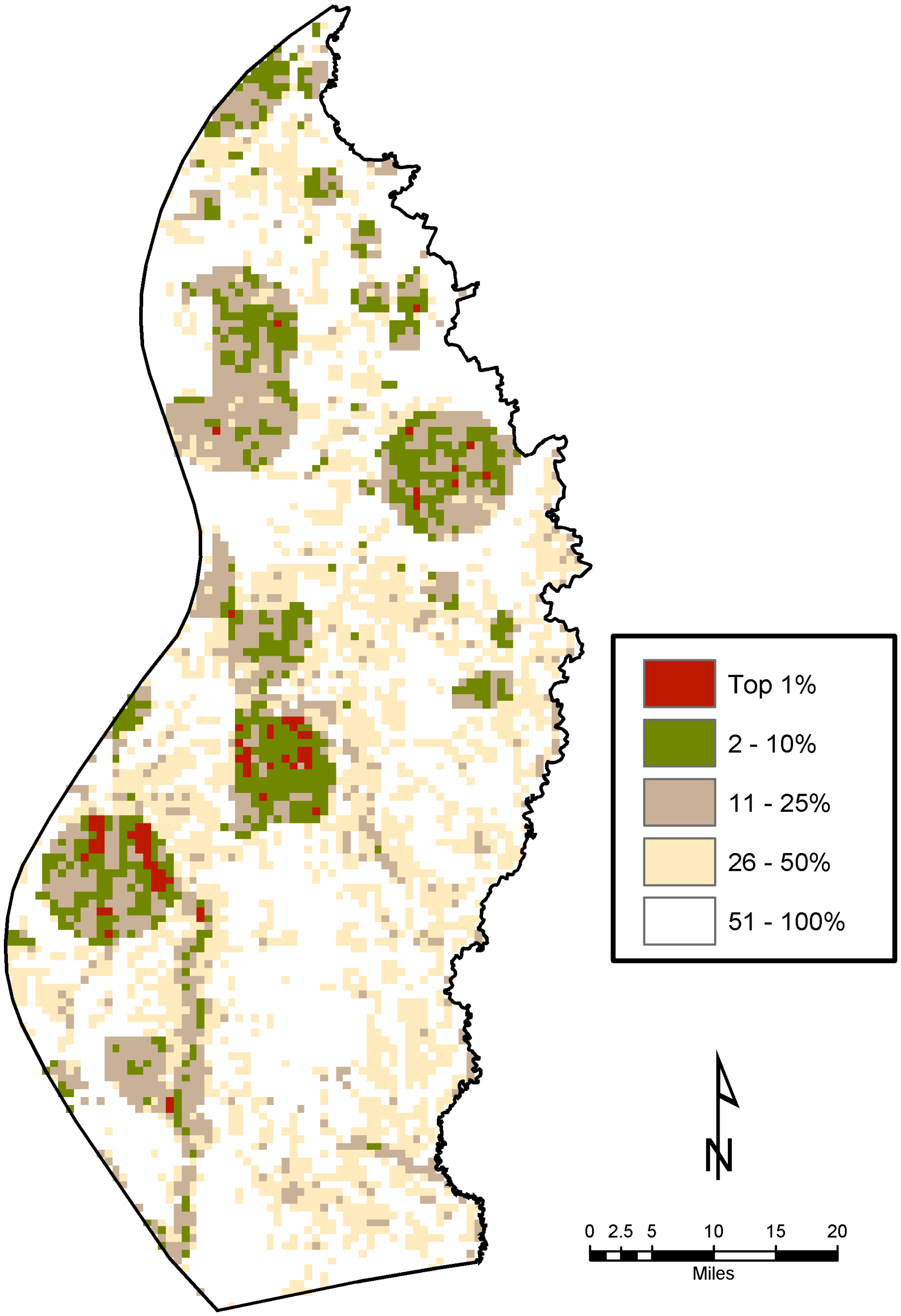

Figure 18. Coastal Plains and Flatwoods Western Gulf Section composite map. A separate figure (Figure 8) shows the entire state. Those areas identified in red as the top 1% represent higher ecological importance, those identified in white as 51-100% represent lower ecological importance.

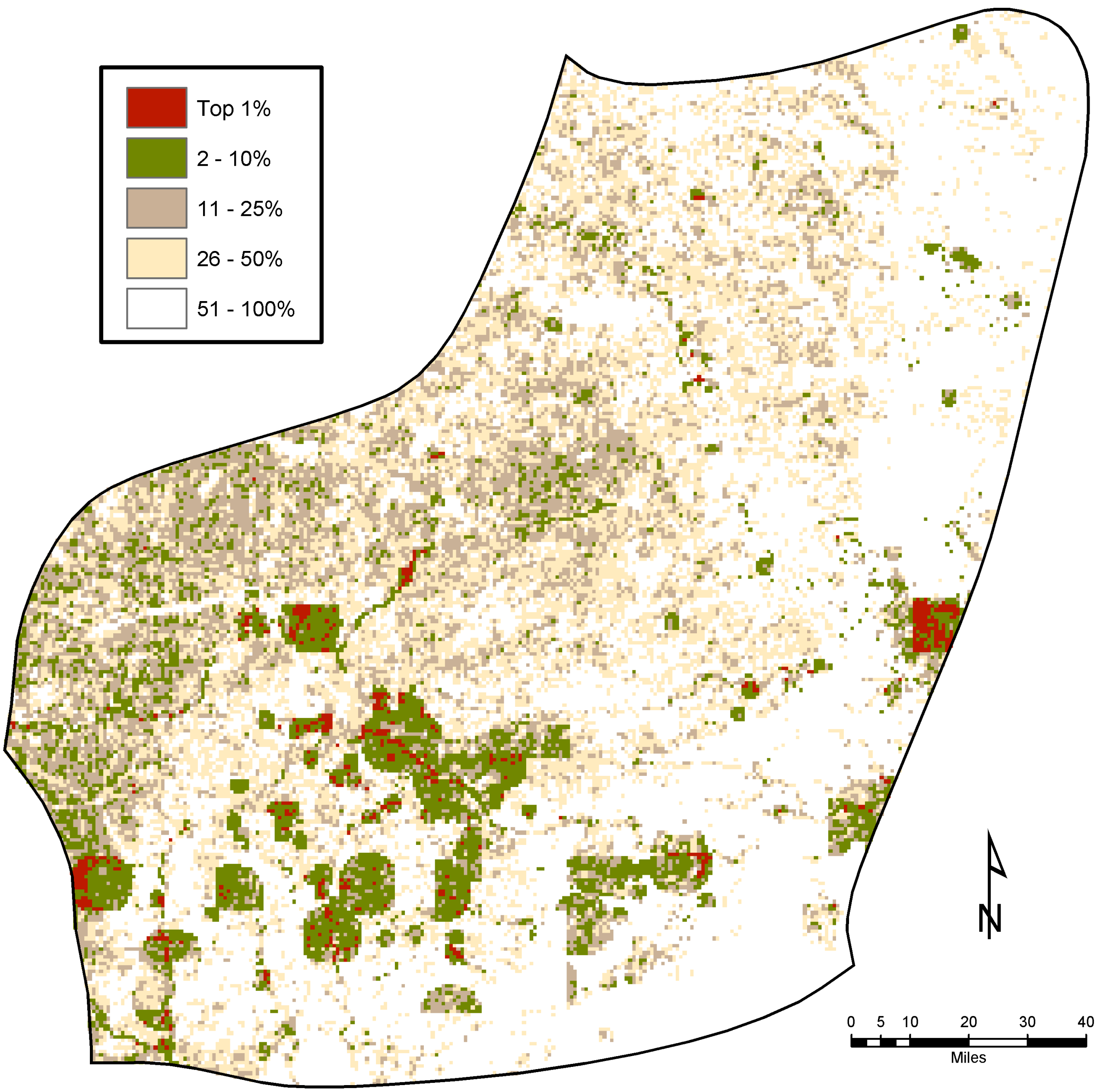

Figure 19. Edwards Plateau composite map. A separate figure ([Figure 8]()) shows the entire state. Those areas identified in red as the top 1% represent higher ecological importance, those identified in white as 51-100% represent lower ecological importance.

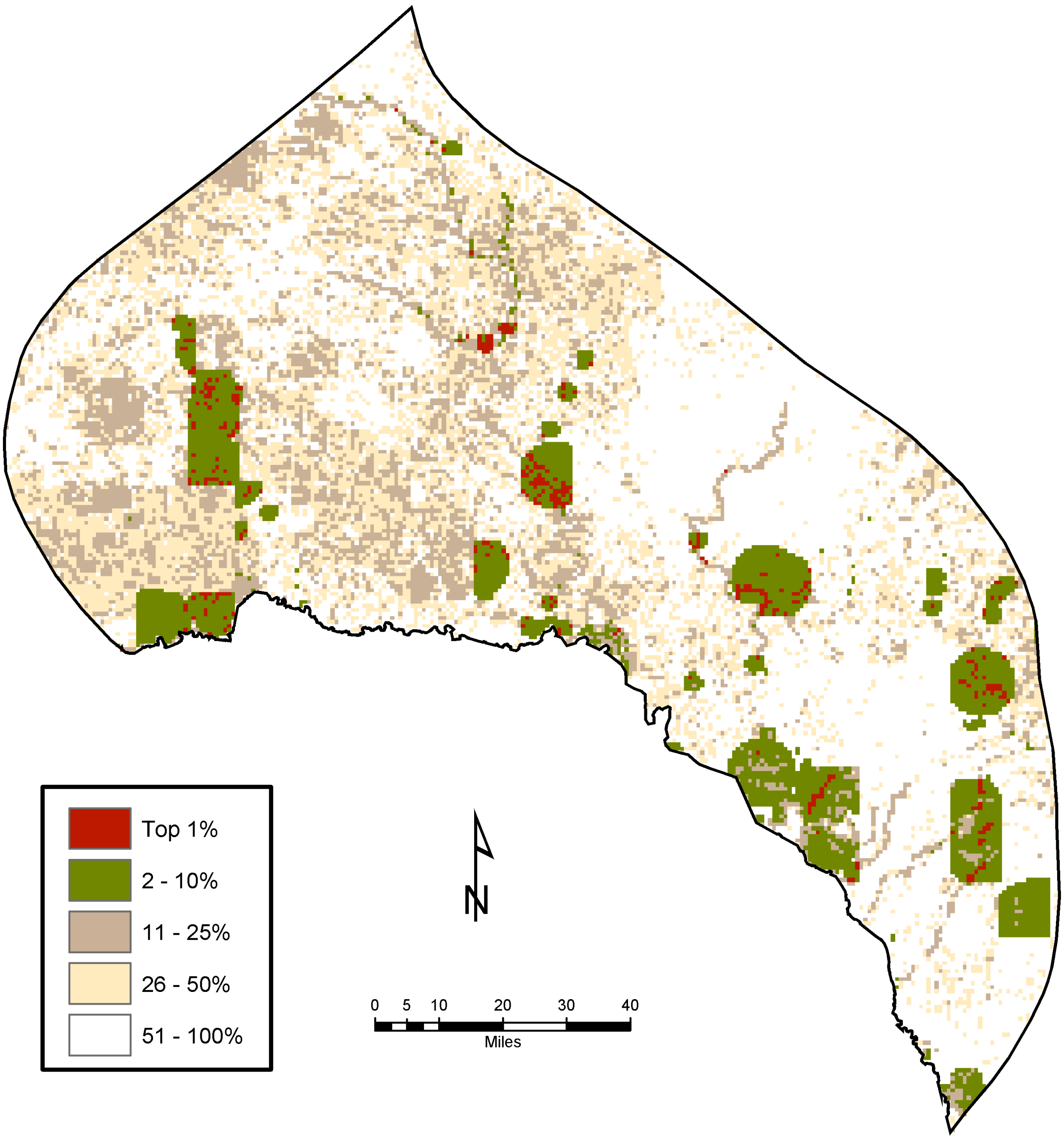

Figure 20. Stockton Plateau composite map. A separate figure (Figure 8) shows the entire state. Those areas identified in red as the top 1% represent higher ecological importance, those identified in white as 51-100% represent lower ecological importance.

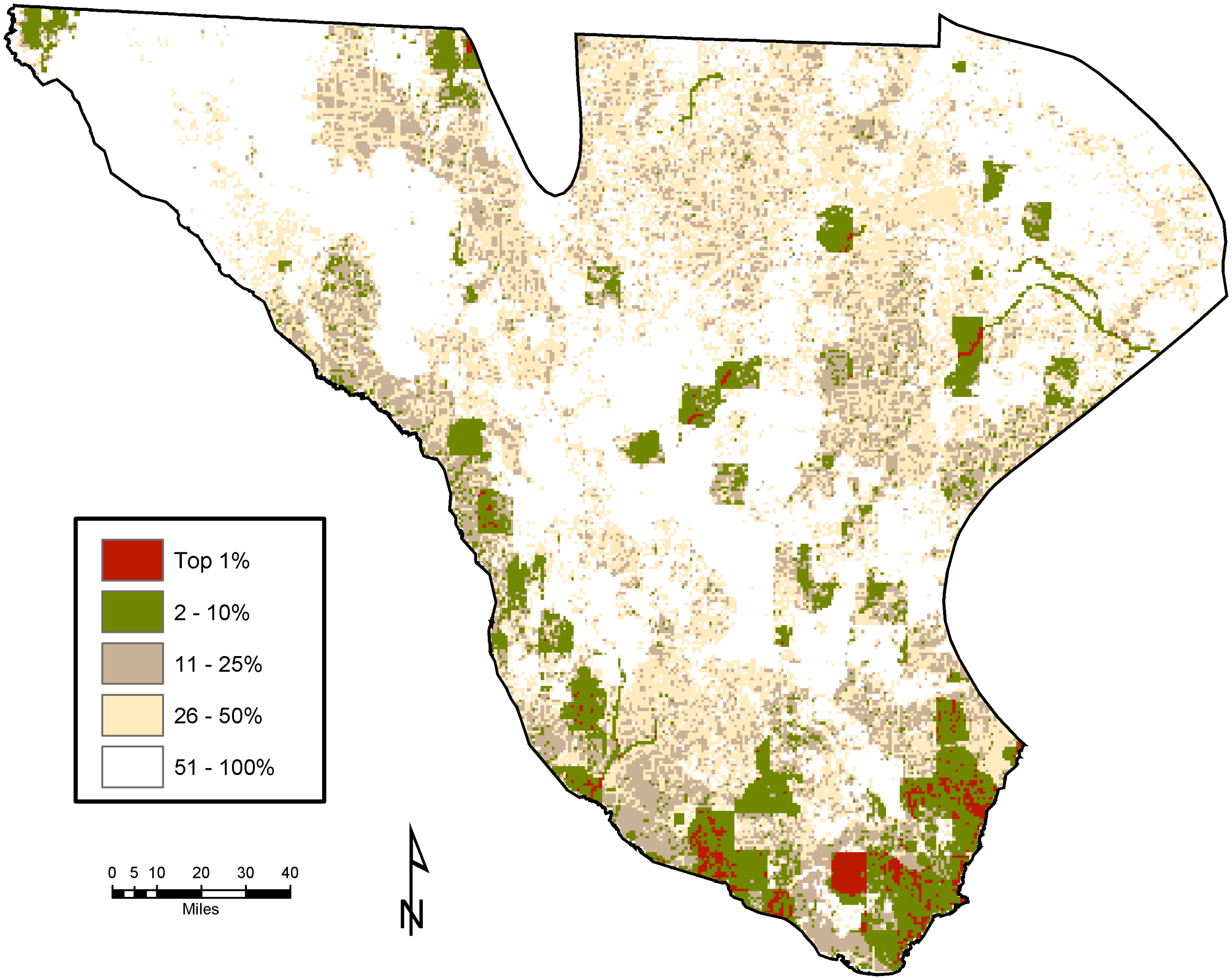

Figure 21. Chihuahuan Desert Basin and Range composite map. A separate figure (Figure 8) shows the entire state. Those areas identified in red as the top 1% represent higher ecological importance, those identified in white as 51-100% represent lower ecological importance.

3.4.1.14 Sacramento-Manzano Mountain

The Sacramento-Manzano Mountain ecoregion is represented in Texas, but extends into New Mexico and Arizona. In this small ecoregion, the highly important areas occur near the Guadalupe Mountains (Figure 22).

3.4.1.15 Louisiana Coast Prairies and Marshes

The Louisiana Coast Prairies and Marshes ecoregion is represented as a small wedge in eastern Texas, but extends further into Louisiana. There are a few areas that are within the top 1% and 10% for ecological importance near the Louisiana border (Figure 23).

3.4.1.16 Eastern Gulf Prairies and Marshes

The Eastern Gulf Prairies and Marshes ecoregion contains highly ecologically important areas on the coastline in the eastern portion ecoregion (Figure 24). The Houston metropolitan area is located on western border of this ecoregion. A relatively large ecological area with a high degree of rarity, is located just north of Galveston Bay.

3.4.1.17 Central Gulf Prairies and Marshes

The Central Gulf Prairies and Marshes ecoregion represents a large portion of the Texas coastline. Several important ecological areas, mostly representing riparian areas or coastal areas appear in this ecoregion (Figure 25).

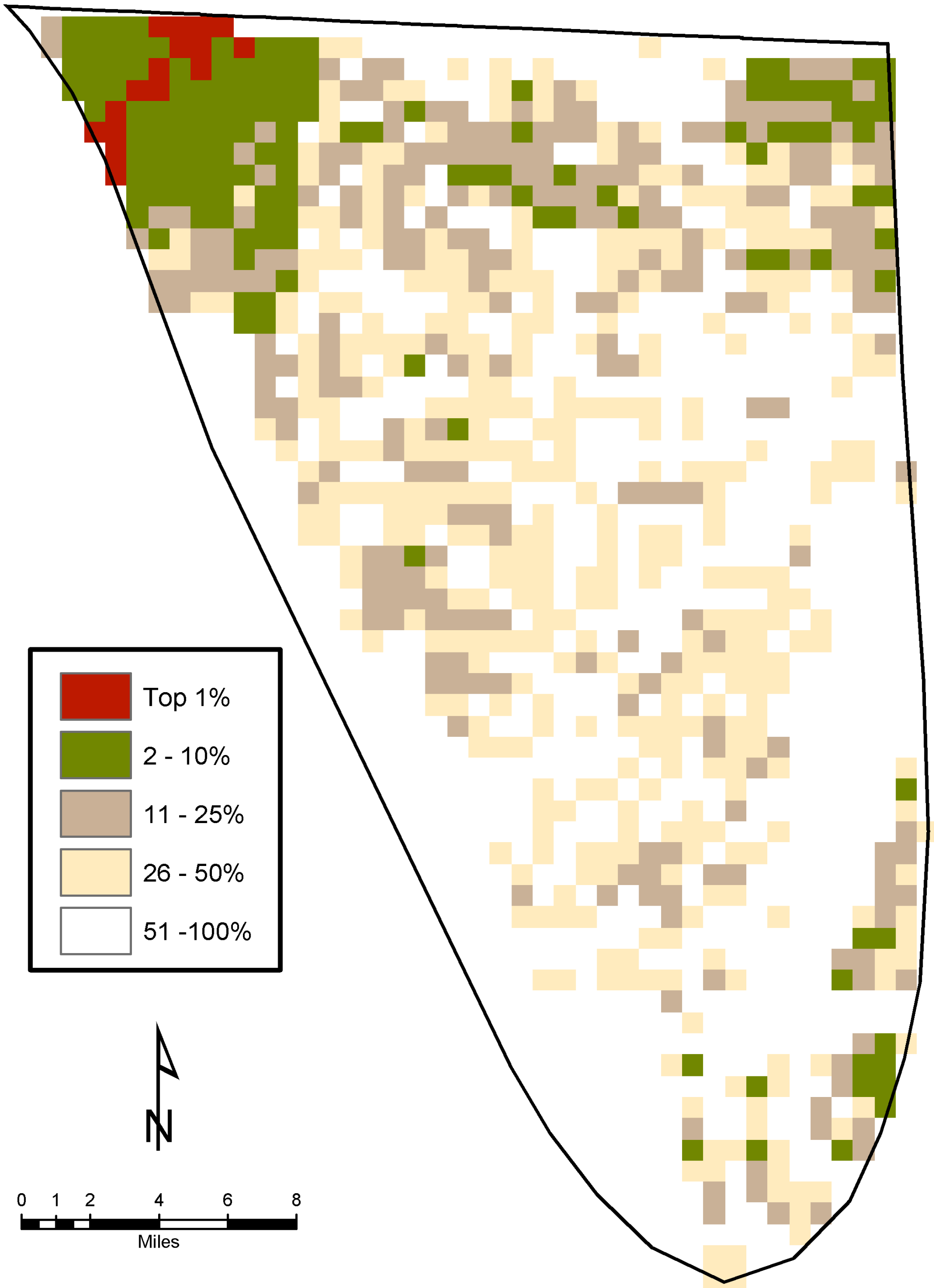

Figure 22. Sacramento-Manzano Mountain composite map. A separate figure (Figure 8) shows the entire state. Those areas identified in red as the top 1% represent higher ecological importance, those identified in white as 51-100% represent lower ecological importance.

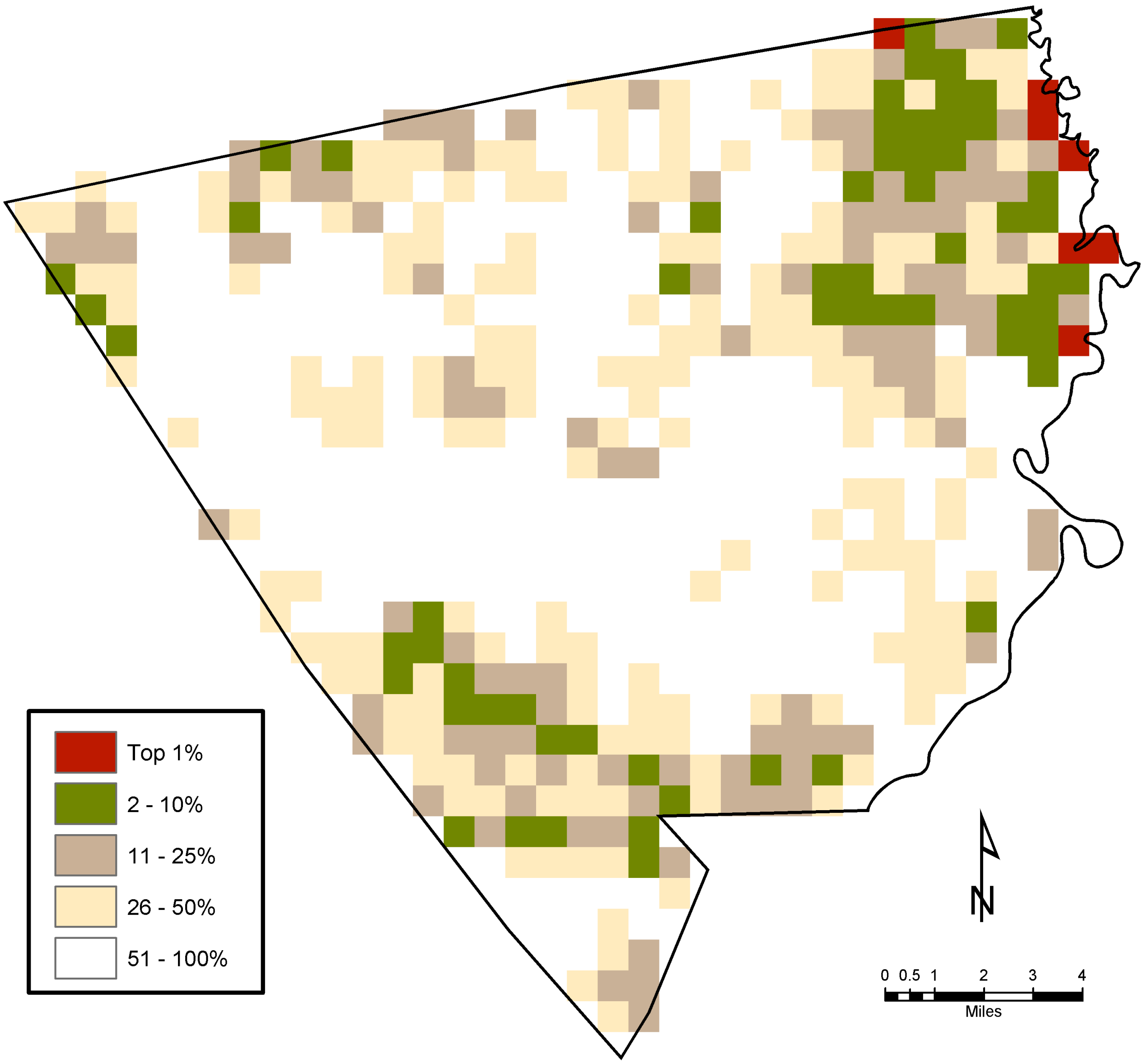

Figure 23. Louisiana Coast Prairies and Marshes composite map. A separate figure (Figure 8) shows the entire state. Those areas identified in red as the top 1% represent higher ecological importance, those identified in white as 51-100% represent lower ecological importance.

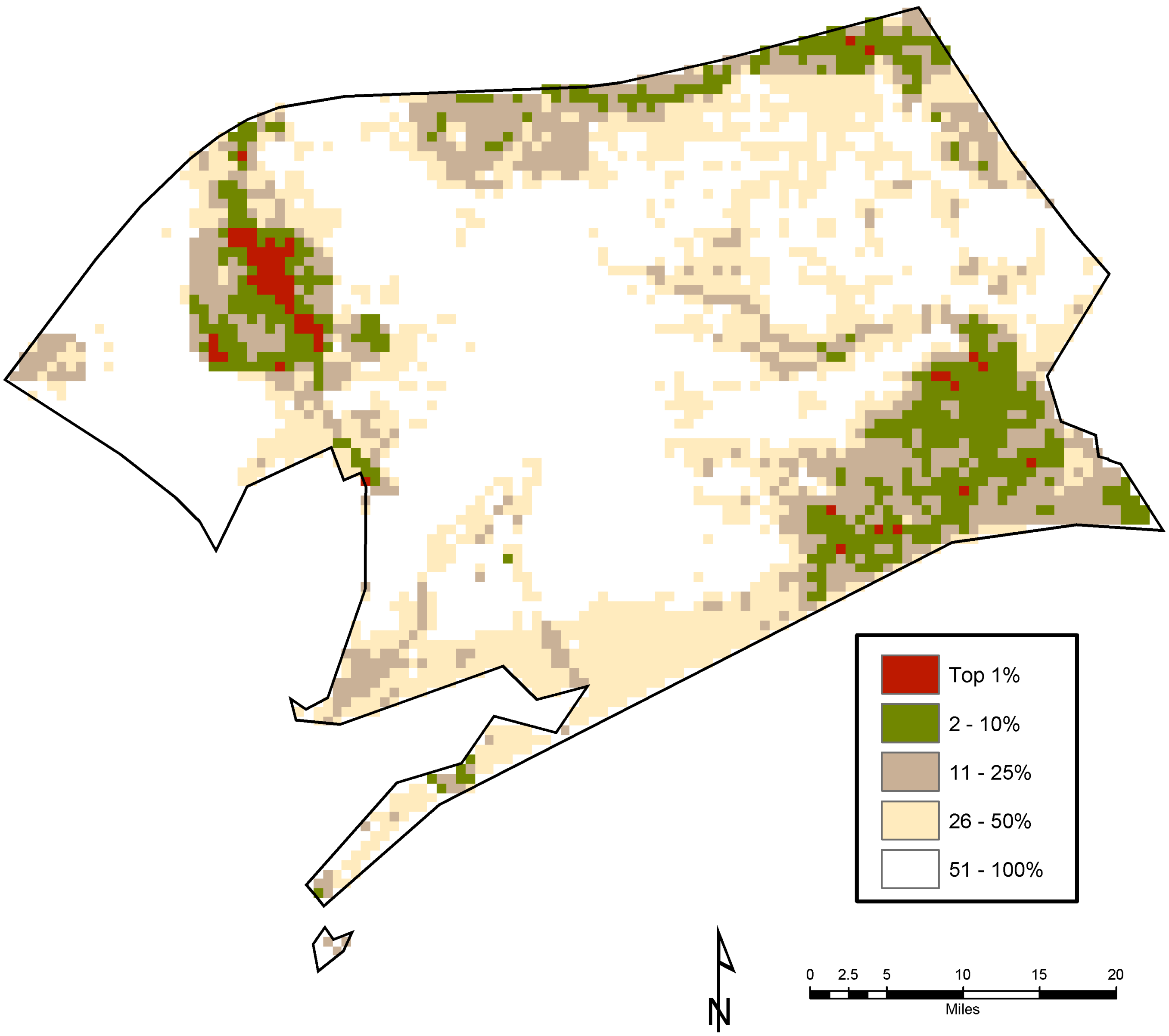

Figure 24. Eastern Gulf Prairies and Marshes composite map. A separate figure (Figure 8) shows the entire state. Those areas identified in red as the top 1% represent higher ecological importance, those identified in white as 51-100% represent lower ecological importance.

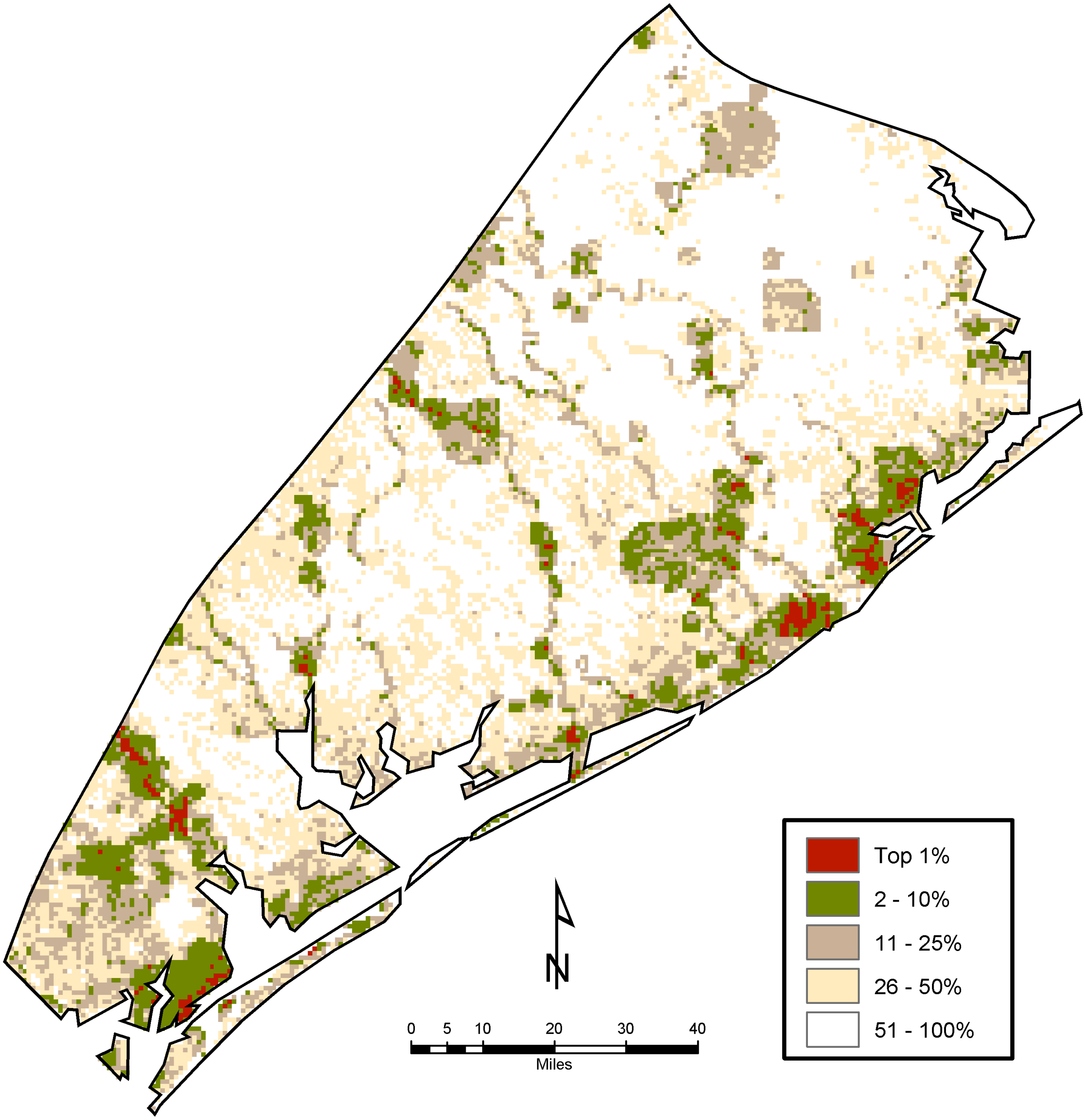

Figure 25. Central Gulf Prairies and Marshes composite map. A separate figure ([Figure 8](#)) shows the entire state. Those areas identified in red as the top 1% represent higher ecological importance, those identified in white as 51-100% represent lower ecological importance.

3.4.1.18 Southern Gulf Prairies and Marshes

The Southern Gulf Prairies and Marshes ecoregion represents the southern portion of the Texas coast and includes South Padre Island. Several ecologically important areas occur on the barrier islands as well as being scattered throughout the ecoregion near the coastline (Figure 26).

3.4.2 Overlays

The TEAP results can be used in conjunction with other databases to show where public lands (Figure 27) or transportation corridors (Figure 28) or watershed boundaries (Figure 29) are in relation to the ecologically important areas identified using TEAP. Each TERS agency can use the TEAP and data and overlay other GIS layers of interest. For example, Figure 29 shows the composite TEAP map with 6-digit HUCs overlaid.

3.4.3 Accuracy Assessment

Figure 30 shows the overlap between highly ranked TEAP composite layer pixels and The Conservancy portfolio locations. As mentioned in Section 2.0, the Tamaulipan Thornscrub and Crosstimbers and Southern Tallgrass Prairie portfolio locations are excluded. In general, highly scored TEAP locations corresponded to the locations of The Conservancy portfolio sites. Correspondence was particularly high for pixels in classes 26 to 30 which represent TEAP composite scores of 251 to 300 (Figure 31a). At lower ranked TEAP composite layer locations, the match between TEAP and The Conservancy portfolio sites is lower. This relationship can also be expressed as a percentage of the TEAP pixel classes residing inside or outside The

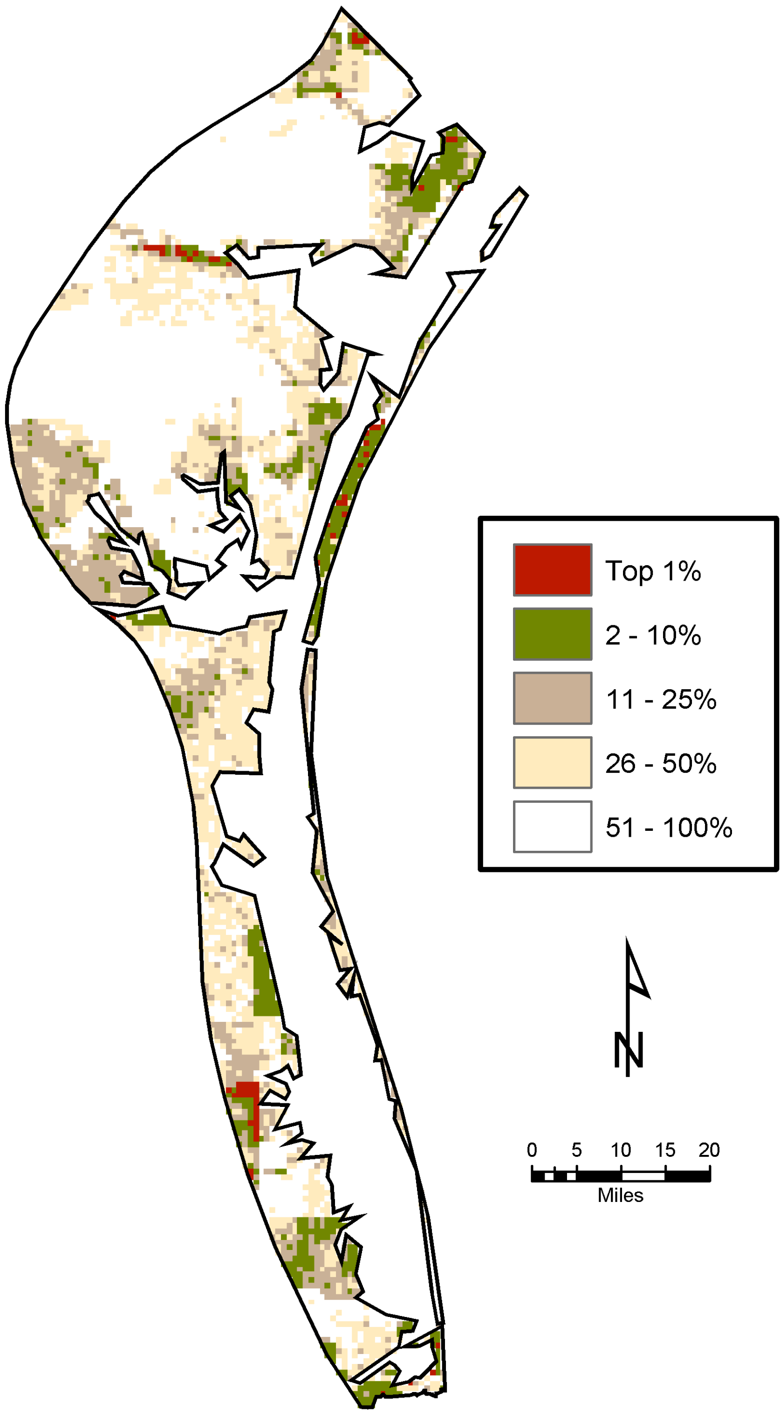

Figure 26. Southern Gulf Prairies and Marshes composite map. A separate figure (Figure 8) shows the entire state. Those areas identified in red as the top 1% represent higher ecological importance, those identified in white as 51-100% represent lower ecological importance.

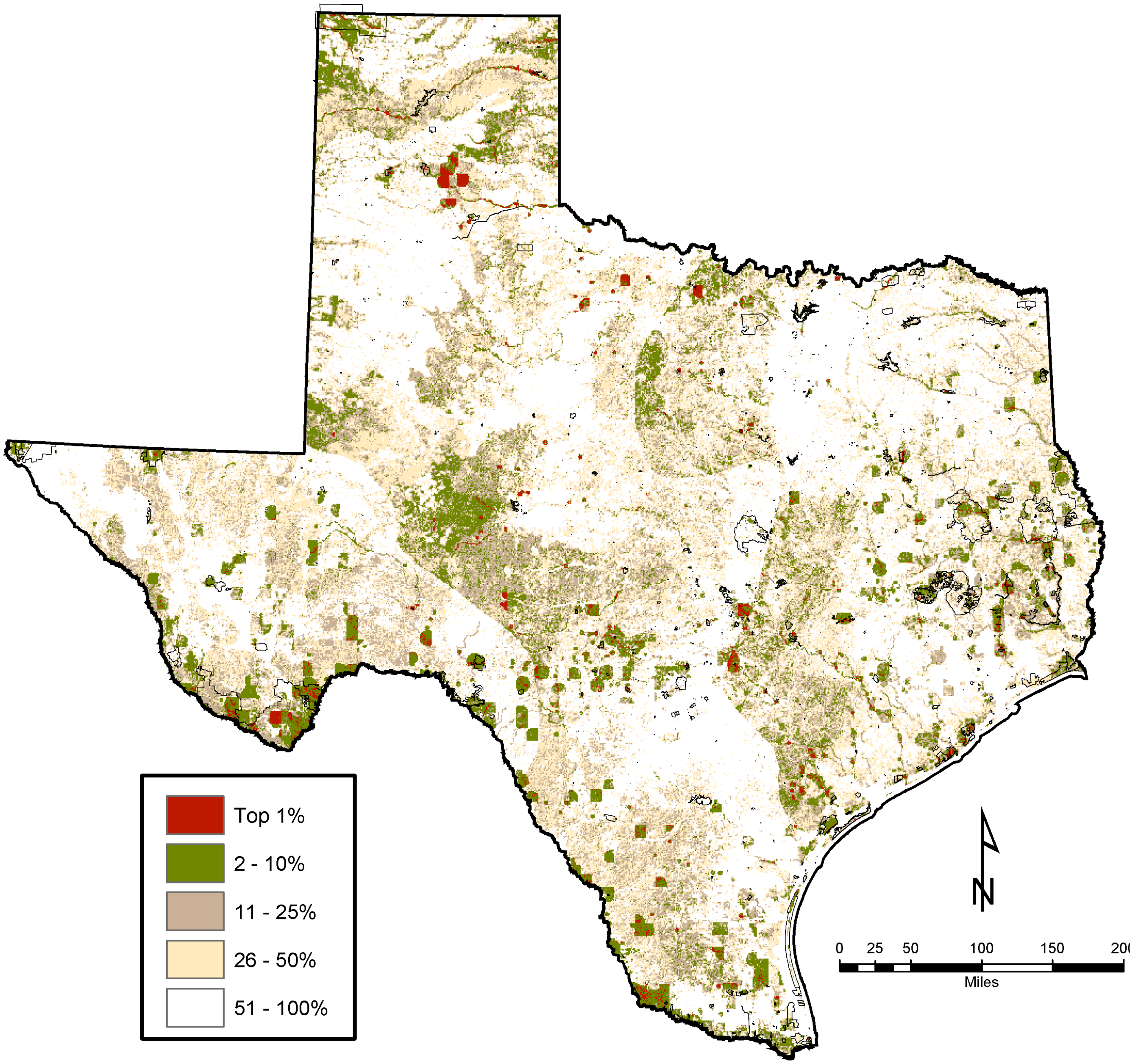

Figure 27. Composite map with public lands overlay. Public lands include National and State Parks, National Forests and Grasslands, Department of Defense lands, and National Wildlife Refuges. Those areas identified in red as the top 1% represent higher ecological importance, those identified in white as 51-100% represent lower ecological importance.

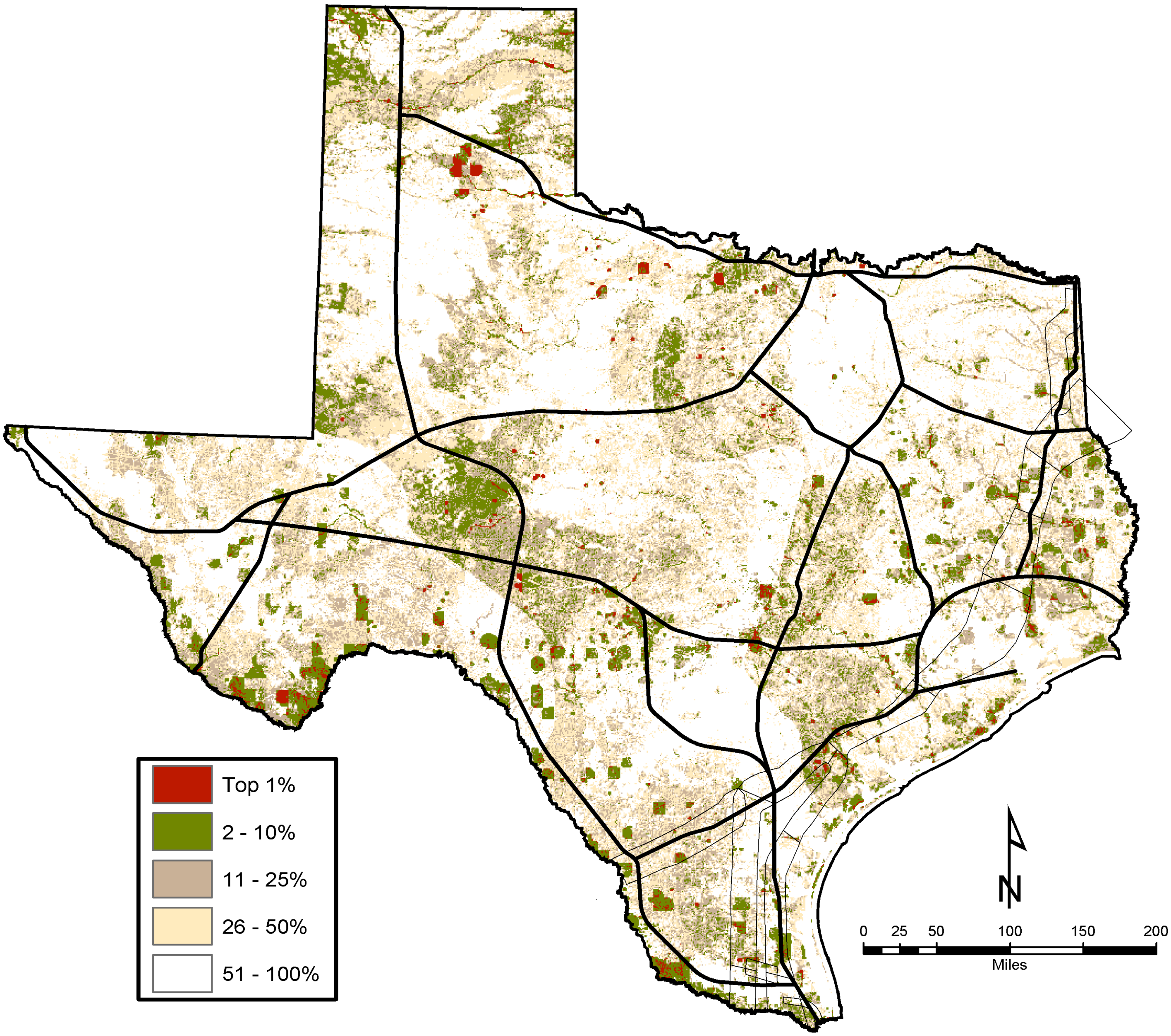

Figure 28. Composite map with transportation corridors overlay. IH69 and Trans Texas Corridor are included. Those areas identified in red as the top 1% represent higher ecological importance, those identified in white as 51-100% represent lower ecological importance.

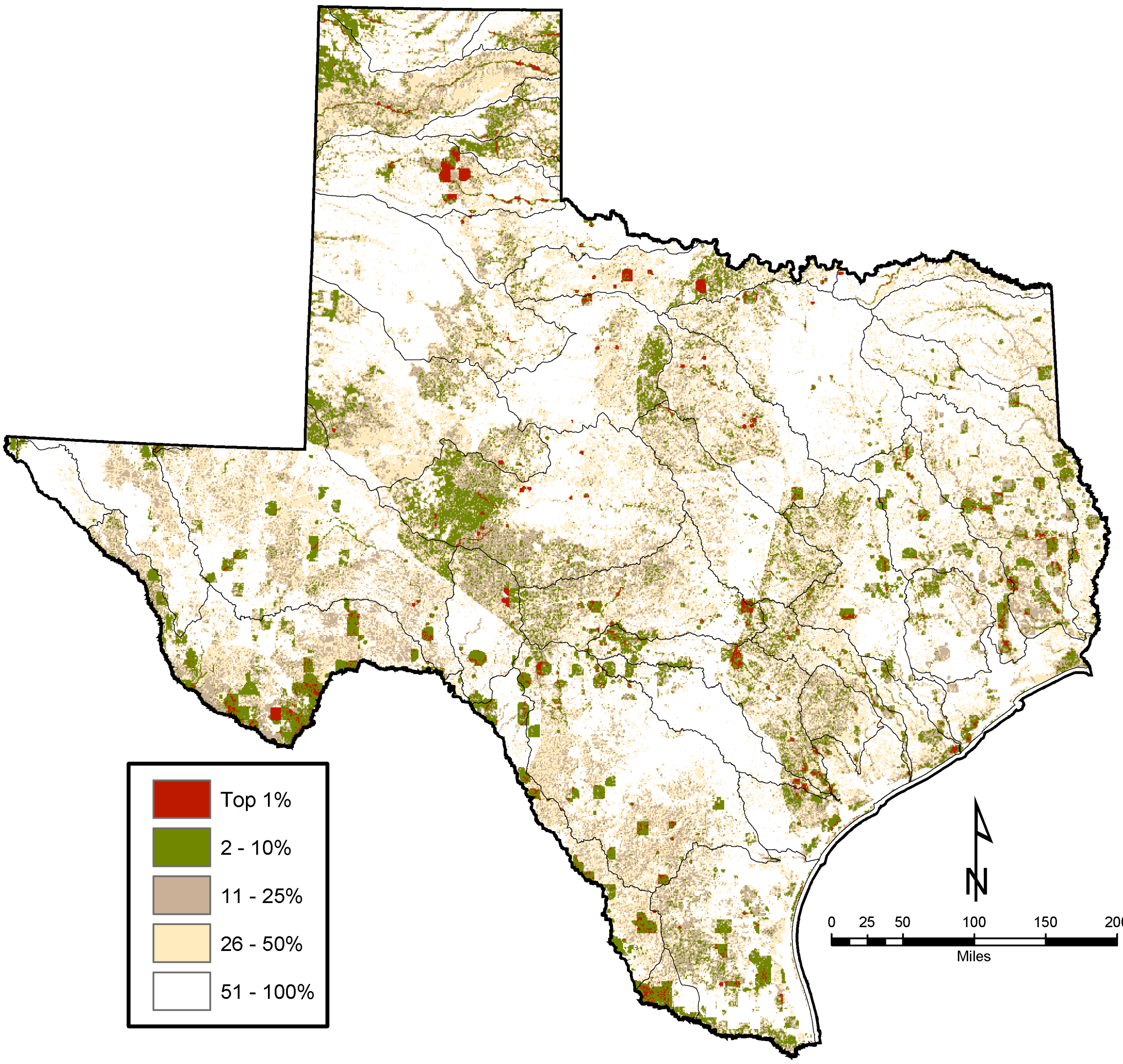

Figure 29. Composite map with watershed boundary overlay. Watershed boundaries reflect 6-digit HUCs. Those areas identified in red as the top 1% represent higher ecological importance, those identified in white as 51-100% represent lower ecological importance.

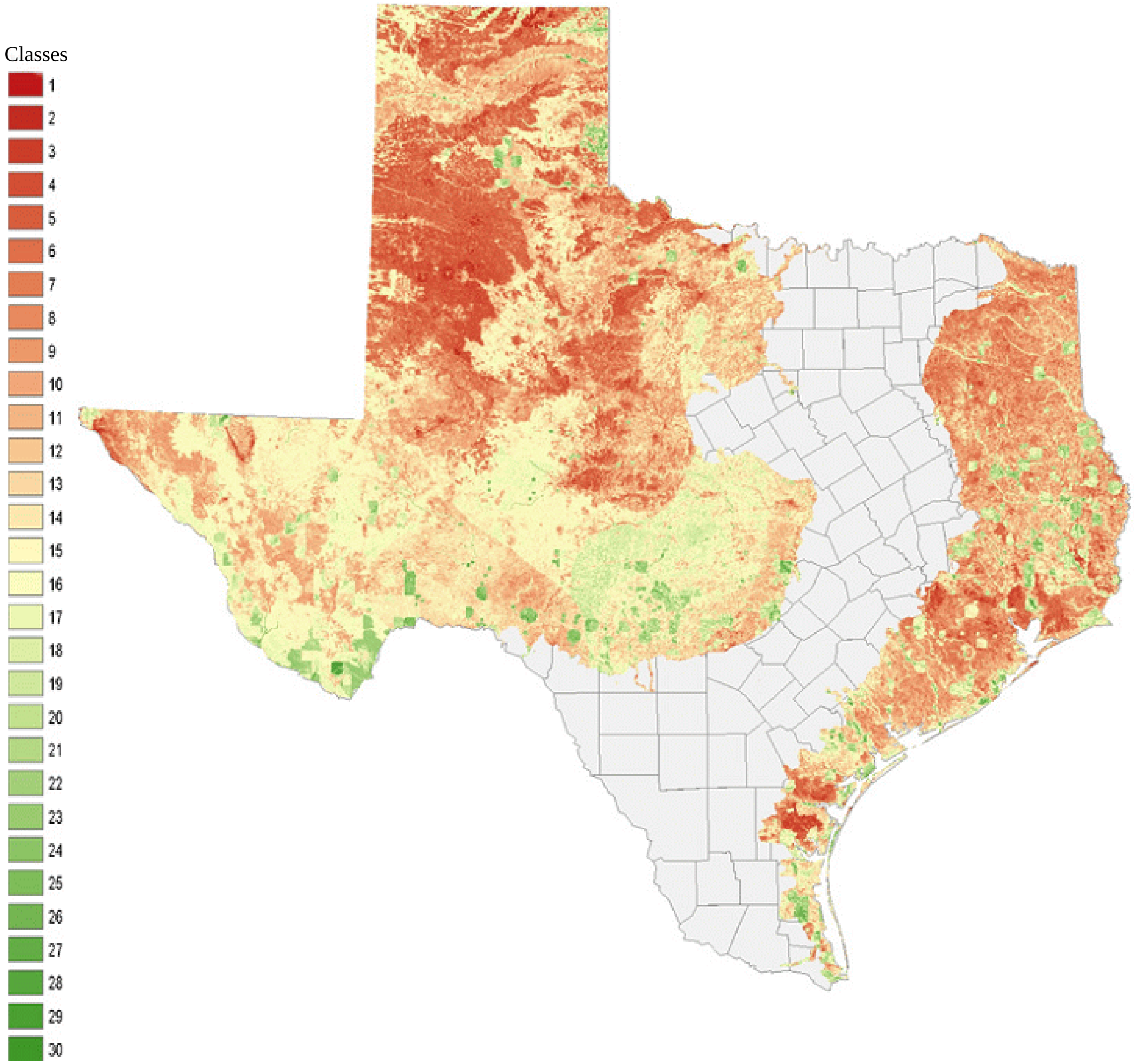

Figure 30. Map depicting areas used for the accuracy assessment. The TNC portfolio does not include the areas in white. The scale reflects the different classes used in the accuracy assessment. A higher class equals a higher TEAP score for that location.

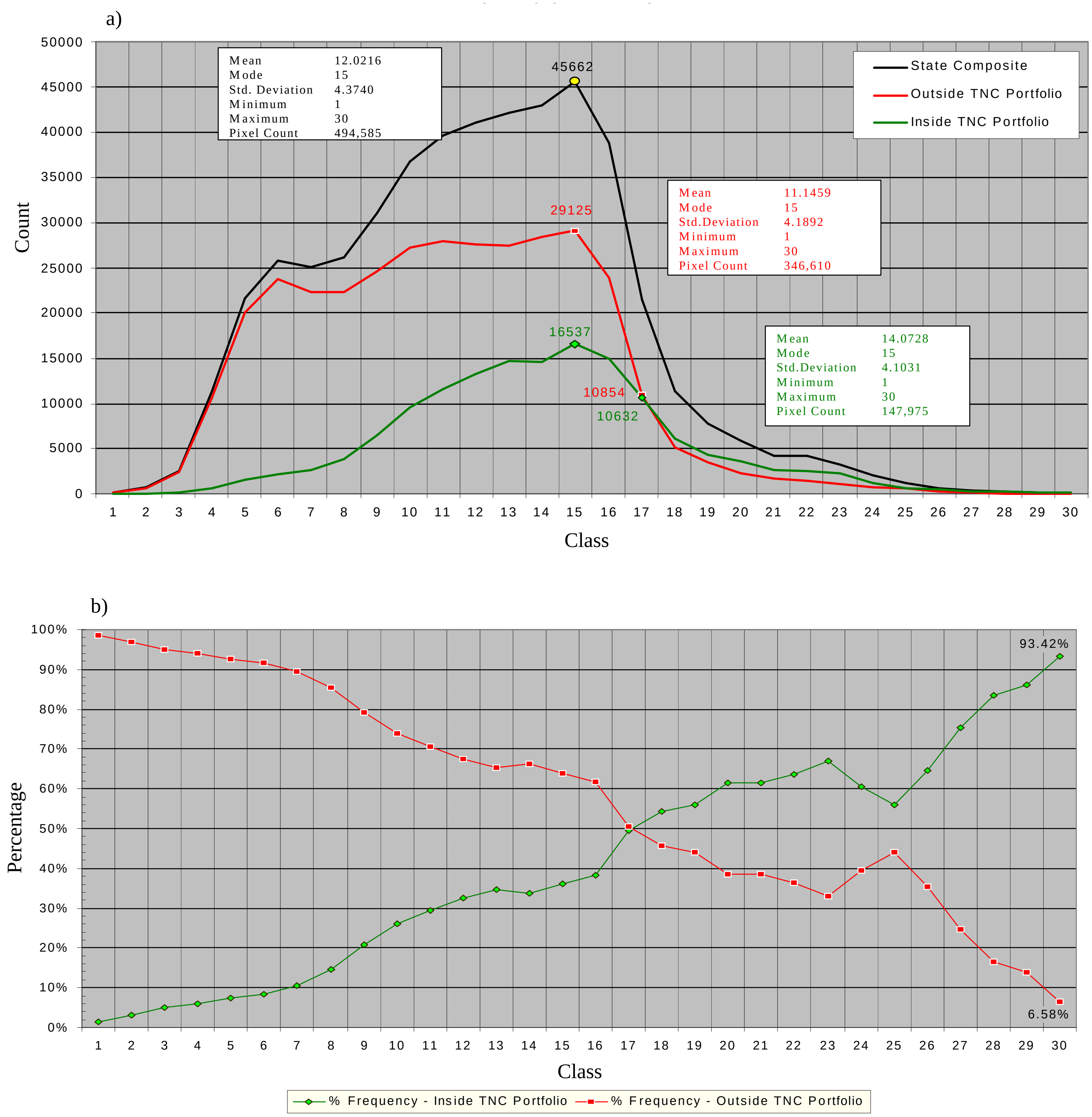

Figure 31. a) Statewide frequencies of TEAP composite scores (by class) that occur inside and outside TNC portfolio; b) statewide frequencies expressed as a percentage of TEAP composite scores occurring inside and outside TNC portfolio. A higher class equals a higher TEAP score for that location.

Conservancy portfolio. For example, Figure 31b shows that 93.42% of the pixels in class 30 (TEAP scores of 291 to 300) are found inside The Conservancy portfolio, whereas only 6.58% of the pixels in this class exist outside The Conservancy's portfolio.

A similar accuracy assessment was performed for the proposed IH69 corridor in Texas (Figures 32 and 33). Most of the IH69 corridor is covered by The Conservancy portfolio except for locations in south Texas (Tamaulipan Thornscrub and Crosstimbers and Southern Tallgrass Prairie) (Figure 32). The results are similar to those seen for the entire state. Highly scored TEAP composite layer locations (approximately classes 24 to 30) showed high correspondence with The Conservancy portfolio sites and lower scored TEAP composite locations showed a weaker match (Figure 33a). All TEAP composite layer pixels in the highest ranked classess (classes 29-30) were located inside The Conservancy portfolio (Figure 33b). The opposite trend is seen for TEAP scores located outside The Conservancy portfolio. For example, 90-100% of the pixels in classes 1 to 7 fall outside The Conservancy porfolio. This is expected since TEAP classified all lands in Texas whereas The Conservancy's conservation process focuses on identifying the highest quality ecological communities only.

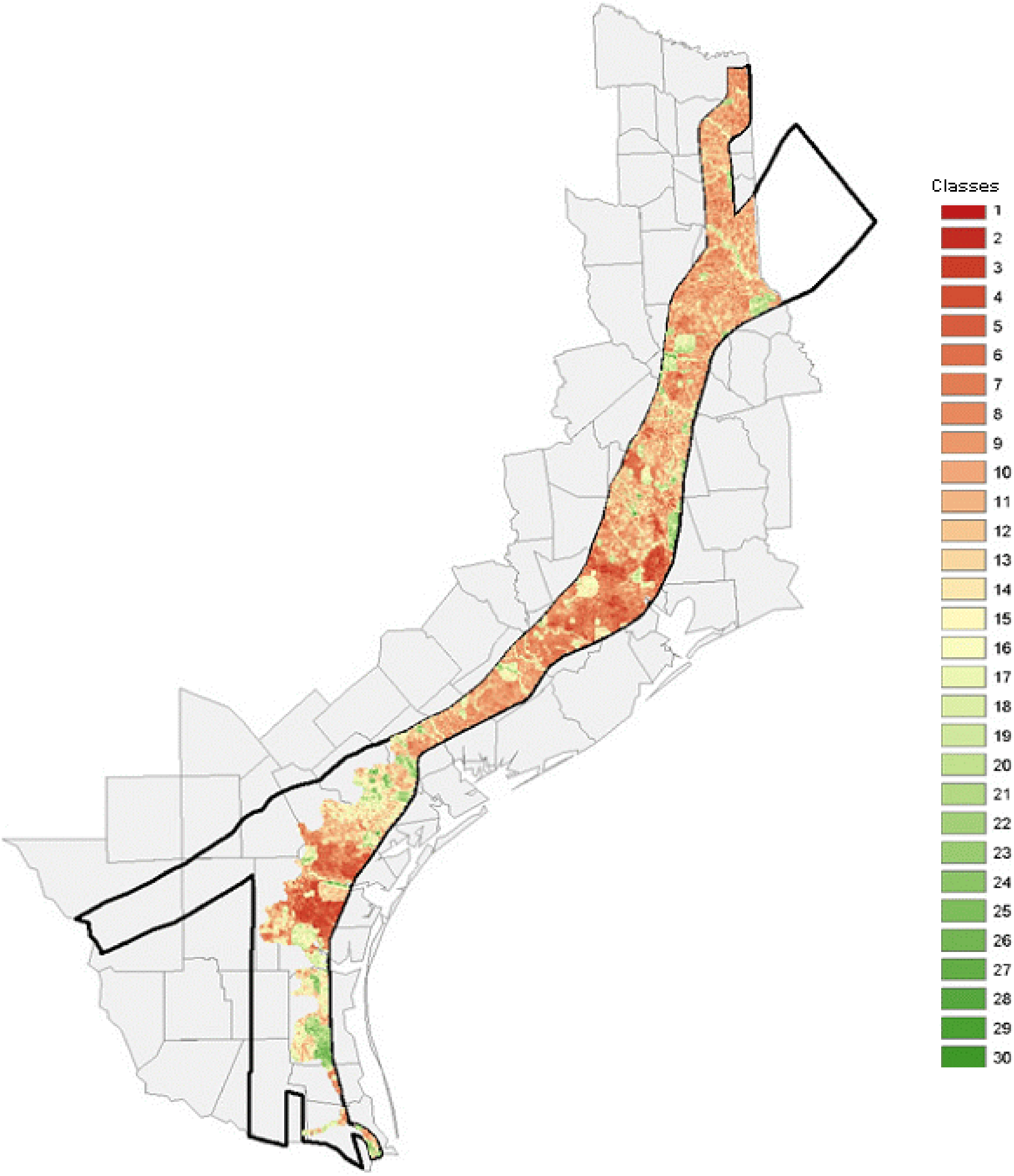

Figure 32. Map of proposed IH69 corridor depicting areas used for the accuracy assessment. The scale reflects the different classes used in the accuracy assessment. A higher class equals a higher TEAP score for that location.

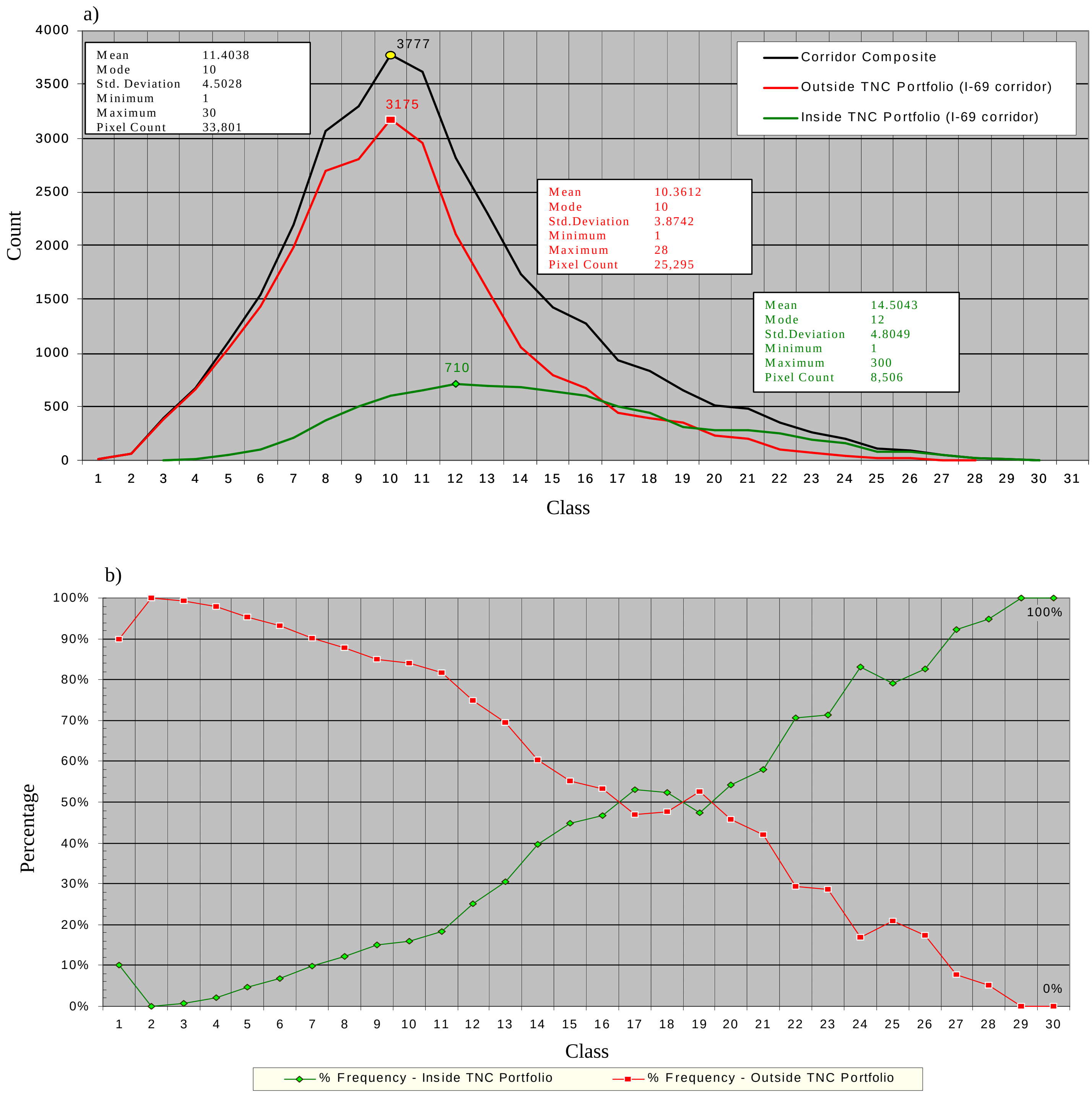

Figure 33. a) IH69 corridor frequencies of TEAP composite scores (by class) that occur inside and outside TNC portfolio; b) IH69 corridor frequencies expressed as a percentage of TEAP composite scores occurring inside and outside TNC portfolio. A higher class equals a higher TEAP score for that location.

4.0 DISCUSSION

Similar to other reports that characterize the environment at a landscape-level (H. John Heinz III Center for Science, Economics and the Environment 2002, Schweiger et al. 2002), the individual sub-layers and main layers selected for TEAP reflect important attributes relating to ecosystem condition, and by extension, ecosystem function. TEAP characterizes ecological conditions in terms of three different aspects of ecosystems using existing data coupled with ecological theory, while recognizing that there are judgements involved in such an enterprise. Given the complexity of ecosystems, these judgements include determining which measures to concentrate on and which to exclude, and communicating the uncertainties and limitations of the data and TEAP analysis.

The TEAP is a relatively simple model that uses stratified data that are combined to give a total or composite picture of the state of Texas at the ecoregion level. Since complicated modeling and analysis tools are less likely to be used in regulatory processes, beneficial properties of GIS assessment tools such as TEAP include 1) simplicity (expert modeling abilities are not needed), 2) use of available data (rather than experimentation), 3) analytical (numerical simulation is not needed), 4) approximation (need matches level of effort), 5) measurable change, and 6) expandability (use in more sophisticated models) (Leibowitz et al. 2000). TEAP assesses and prioritizes locations when information is limited. Due to the scale at which the TEAP was performed it has limitations in utility with regard to regulatory decisions or processes requiring more detail. TEAP is a screening tool that can assist in overall conservation efforts (including project planning, mitigation, preservation, or restoration activities) and to identify areas where more detailed, site-specific data are needed. TEAP results should be used in conjunction with agency-specific information to support decisions. (Schweiger et al. 2002). TEAP should enable managers to consider specific decisions within an ecoregion context.

4.1 Data Limitations

Several limitations of the data and analysis should be noted. No individual sub-layers were removed *a posteriori* from this iteration of the protocol. The limitations and other issues concerning specific sub-layers or their use in the protocol or their application to regulatory processes are discussed, so that they can be modified or excluded in the next iteration of TEAP. It was also felt that by removing individual sub-layers, the composite may only have a few relatively non-ecological sub-layers to account for the majority of a main layer. Multivariate evaluation of the results may yield a clearer picture of the relative contribution of each sub-layer to each of the three main layers and the composite.

The scoring methods per layer and per ecoregion result in an issue at ecoregion boundaries. Two adjacent cells with the same land cover type and the same stressors can score differently in different ecoregions. For example, two cells both have a PAR of 0.123, but cell A could get a score of 75 while cell B could receive a score of 50 because of the differences in their respective ecoregions. The two cells could also have a composite score that is different, even though they are basically the same. The reverse is also true; sites with the same composite score could end up in a different category for similar reasons. Adjacent cells A and B both have a composite score of 225, but cell A is in the top 1% cell (colored red) in its ecoregion, but cell B scores in the top 10% cell (colored green) in an adjacent ecoregion.

Each sub-layer within the diversity layer represents different, but somewhat overlapping, attributes of diversity, that when combined, gives a broader picture of diversity in each ecoregion. It can be true that there is a dichotomy between contiguous area and appropriate land cover. These are reasons why the TEAP (and CrEAM) is a stratified approach (i.e., equally-weighted sub-layers feed into layers which are then combined into a composite).

Kuchler (1964) data was used in the diversity and sustainability layers. The comparison between the PNV (Kuchler 1964) and 1992 NLCD is the most common method of describing the original spatial distribution of land cover and current conditions (Geneletti 2003). In addition, maintaining vegetation in proportion to its former, pre-settlement abundance is a goal of biodiversity conservation (Geneletti 2003).

The TXBCD is an observational data set that does not specifically consider communities. It is not comprehensive or synoptic like the GIS coverages. This is the reason that the TXBCD (or any other individual sub-layer, for that matter) was not used to exclusively represent rarity, but was combined with vegetation rarity (using NLCD), and is included as a separate sub-layer of equal weight in the rarity main layer. Other studies use measures of rarity, and highlight its relevance, especially for biodiversity conservation. However, there is no consensus on the attributes to include for its evaluation (Geneletti 2003).

Actual habitat information is better than somewhat arbitrary buffers around species observation points. However, this type of data does not exist statewide, although gap analysis data may be available in the future to address this concern. Other databases or scientific studies may exist, but did not meet the general guideline of TEAP to use pre-existing data that was available statewide. The reason for not using localized study data is to avoid the bias that results because some species are better studied than others. For example, a great deal is known about the organisms that inhabit the Edwards Aquifer and recharge zone of the Edwards Plateau ecoregion (Figure 19). However, biota in other portions of this ecoregion may not be as well studied or have systematic data available. EPA Region 5 found a similar situation in its analysis where one state had a much more active monitoring and data collection program than other states. EPA Region 5 addressed this by using multiple measures or sub-layers to characterize rarity.

The TEAP sub-layers do not explicitly account for supporting habitat for species (versus the actual observation point), although the contiguous size of undeveloped land (Figure B2) describes polygons of adjacent undeveloped land cover types. While it is correct that any land cover patch is generally influenced in some way by its adjacent neighboring patches, the TEAP is not able to explicitly incorporate adjacency effects as would be possible in a dynamic simulation model. The TEAP is a static model which characterizes the landscape through a mono-temporal multi-criteria evaluation approach. Detailed spatial and temporal dynamics between landscape patches cannot be modeled in this class of static models. Given the goals and objectives of TERS, it is unlikely that a dynamic model would provide a better solution than the type of model used.

Unlike EPA Region 5, Texas does not contain any natural lakes (other than isolated playa basins). Therefore, the open water land cover types (i.e., reservoirs) had to be excluded from sustainability sub-layers such as regularity of ecosystem boundary. It is a long and tedious manual process in GIS to “mask out” these areas so that only the shoreline was used. Including the entire area of these reservoirs (rather than just the shoreline) could tend to skew the area included in the one percentile fraction of the total area in an ecoregion.

The watershed obstruction sub-layer calculates dams per stream miles within each HUC whereas the water quality sub-layer uses actual stream segments. These two sub-layers should be more consistent in the next iteration because both could use stream segments (vs HUCs). However, a significant amount of technical assistance would be required to modify the calculations for these two layers for the next iteration of TEAP.

The road density sub-layer did not intentionally include or exclude water bodies. Cells that had zero roads scored 100, therefore cells that are all water are scored 100 (predominately found in the coastal areas).

In the urban/agriculture disturbance sub-layer (Figure B19), a 600 m buffer around urban and agricultural areas may tend to mask the presence of riparian and greenbelt areas. Though highly susceptible to development pressures, these areas may be among the most important to maintain and protect, especially for adequate water quality necessary to sustain aquatic species and to reduce downstream pollutant transport. TEAP is not intended to discourage use or designation of buffer zones around riparian, urban, or recreation areas. TEAP should point out places for conservation and enhancement (especially in terms of potentially restoring landscape connectivity) in areas that are currently not sustainable without intensive human management.

Given the available data and timeline, the EPA Region 5 model was at a scale (300 m^2) that allowed them to pick out a single or a few pixels of important ecological areas in or near cities (e.g., within the top 25% of all sites in the midwest.). This iteration of TEAP did not use such a fine scale resolution because of data quality and computer calculation time.

4.2 Accuracy Assessment

The accuracy assessment was performed by The Conservancy, an independent entitynoy involved with the calculations of the TEAP main and composite layers. The portfolio sites used in the accuracy assessment were derived independently from the TEAP using The Conservancy's process. Both TEAP and The Conservancy's processes use GIS information at some level; however, The Conservancy's process also includes field investigations whereas TEAP does not. As explained in the results section, the match between The Conservancy's portfolio sites and highly scored TEAP composite locations is good; however, there is less of a match at lower TEAP scores. This may be due to the fact that The Conservancy's process is designed to identify the highest quality or rare ecological communities for protection rather than identifying lower quality sites for restoration or mitigation process opportunities. It is difficult to determine the degree or "goodness" of the match between TEAP and The Conservancy without further field investigations. The decision to proceed with field investigations depends on the priority of such investigations for the TERS member agencies and the usefulness of these lower scored TEAP composite locations to agency programs (e.g., agencies looking for restoration opportunities).

Further analysis using multivariate statistics is needed to further verify the results of TEAP. Future actions such as the application of landscape metrics to study the pattern found at a finer resolution are also recommended to understand the spatial landscape patterns (McGarigal and Marks 1994, Riitters et al. 1995, Hargis et al. 1998, Roy and Tomar 2000, Herzog et al. 2001, Lee et al. 2001, Ochoa-Gaona 2001, Lausch and Herzog 2002).

4.3 Conservation

TEAP uses generally accepted ecological theory as the basis for its analysis. However, an aspect that affects potential conservation and protection of ecologically important locations in Texas regards the protection of large contiguous tracts of land versus protection of small high-value remnants that are possibly unsustainable areas without intense human management. The argument of protecting Several Small or Single Large areas/reserves (SLOSS) has been discussed considerably in the scientific literature (see Ovaskainen 2003). In the end, questions related to the spatial configuration of reserves and how the surrounding matrix was managed became more important as conservation goals.

Conservation is not the primary mission of many regulatory agencies. For these agencies, the TEAP may be useful in meeting NEPA requirements and in making project planning level analyses and decisions.

It seems obvious that planners should avoid negatively impacting ecologically important areas, especially in areas where there are few ecologically important areas remaining. On the other hand, the most threatened and rarest species and communities are often found in areas that TEAP would identify as less important. The key is to strike a balance between protecting and enhancing highly ecologically important areas versus protecting and enhancing vulnerable species/communities in less ecologically important areas.

Eventually, the decision should be determined by several factors. Ovaskainen (2003) suggested that the SLOSS decision should promote 1) maximizing the number of species that will eventually survive, 2) maximizing the number of currently occurring species, 3) lengthening species time to extinction, and 4) maximizing metapopulation capacity. Similarly, Noss and

Csuti (1994) proposed that 1) critical ecological processes must be maintained, 2) goals and objectives must come from an ecological understanding of the system, 3) external threats must be minimized and external benefits maximized, 4) evolutionary processes should be conserved, and 5) management must be adaptive and minimally intrusive. Harris et al. (1996) and Noss (1996) suggest a connectivity approach to protect landscapes from further fragmentation and to restore connectivity to culturally fragmented landscapes, where possible. Linking such areas may enhance landscape connectivity (e.g., organism dispersal, optimal foraging areas) and reduce the effects of fragmentation (Beier and Noss 1998, Hoctor et al. 2000, Swenson and Franklin 2000).

The ecologically important areas identified through TEAP do not represent areas that, if left undisturbed, would capture all of the remaining biodiversity in the state, nor does it give license to destroy areas that have lower TEAP scores of ecological importance. The use of TEAP would be the first step in avoidance of impacts, not the last. TEAP identifies the top 1% ecologically important areas in each ecoregion and provides information to aid streamlining agency decisions used to protect the biodiversity of Texas. When communicating with decision-makers concerning the results of TEAP, protecting (or avoiding) every square inch of an area falling in the 1% category does not necessarily protect biodiversity *per se*. It can, however, help protect places that make a significant contribution to the biodiversity of Texas.

5.0 CONCLUSIONS

5.1 Streamlining

The TEAP effort supports streamlining and the EO 13274 by providing a tool agencies can use to rapidly assess some of the environmental impacts of large projects, including transportation projects. The TEAP accomplishes one of the goals of TERS, which is to develop an ecosystem-based tool to assist in identifying important ecological areas in the state for use in the planning of large scale projects. It may also aid in alternatives analysis, some compensatory mitigation, and preservation.

Another goal of the TERS is to improve the overall quality of agency decision-making, with respect to the environmental concerns, in the state of Texas. The information provided by TEAP better informs agencies facilitating better decisions.

5.2 Next Steps

Large-scale projects present many special problems. The following are obstacles to achieving adequate mitigation of environmental impacts: 1) They often affect diverse habitats, land forms and watersheds, 2) Adequate amounts or types of lands needed for appropriate compensatory action may not be easily accessible, and 3) They may intersect numerous regulatory agency jurisdictions that must be addressed (Reid and Murphy 1995). Linear projects are a special challenge because the avoidance of impacts in one segment may define the impact in the next. Identification of the most important resources present for an entire project is a tool that can be used to avoid impacts, minimize impacts, identify potential compensatory mitigation, and select the least environmental damaging project alternative.

Large projects such as IH69, challenge agency staffing, funding, and the ability to provide timely decisions if conducted in a "business-as-usual" manner. Regulatory agency authority and policy may or may not provide guidance to deal with the demands associated with very large and complex projects.

In the past, impacts of public works projects have not been evaluated on an ecoregion scale in Texas. Inclusion of ecoregion information, such as that found in the TEAP, into the planning process of large public works projects facilitates project impact analysis and the mitigation of impacts while realizing conservation of ecologically important lands. This tool may help streamline the project development process through early identification of project impacts, and enhances the capability of avoidance and minimization of those impacts.

TEAP has great potential for enhancing environmental impact analysis. However, it still needs to be validated. TEAP should be updated approximately every two years to maximize utility. This will allow the performance of trend analysis as new data becomes available. The results described in this report can be used in discussions for mitigation opportunities and identification of key locations for more effective species protection (Abbitt et al. 2000). For example, TEAP information can be of assistance in locating, designing and establishing mitigation areas, mitigation banks, or other conservation areas. Finally, TEAP identifies strategic indicators that can be modified in subsequent iterations, can be compared across time periods, can potentially serve as reference points for project and long range planning, and can provide supplemental data to aid in regulatory discussions. TEAP is not designed to take the place of agency policies and procedures, but to be a supplemental information tool to aid in agency decision making.

6.0 ACKNOWLEDGMENTS

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APPENDIX A
Descriptions of Bailey's Ecoregions
(McNab and Avers 1994)

Table of Contents

Chapter Page

Southeastern Mixed Forest 140
Mid Coastal Plains, Western (Section 231E) 140
Geomorphology 140
Lithology and Stratigraphy 140
Soil Taxa 140
Potential Natural Vegetation 141
Fauna 141
Climate 141
Surface Water Characteristics 141
Disturbance Regimes 141
Land Use 141
Eastern Gulf Prairies and Marshes (Section 231F) 141
Geomorphology 141
Lithology and Stratigraphy 142
Soil Taxa 142
Potential Natural Vegetation 142
Fauna 143
Climate 143
Surface Water Characteristics 143
Disturbance Regimes 143
Land Use 143

Outer Coastal Plain Mixed Forest 143
Louisiana Coast Prairies and Marshes (Section 232E) 143
Geomorphology 143
Lithology and Stratigraphy 144
Soil Taxa 144
Potential Natural Vegetation 144
Fauna 144
Climate 145
Surface Water Characteristics 145
Disturbance Regimes 145
Land Use 145
Coastal Plains and Flatwoods, Western Gulf (Section 232F) 145
Geomorphology 145
Lithology and Stratigraphy 146
Soil Taxa 146

Potential Natural Vegetation 146
Fauna 146
Climate 146
Surface Water Characteristics 147
Disturbance Regimes 147
Land Use 147

Prairie Parkland (Subtropical) 147
Cross Timbers and Prairies (Section 255A) 147
Geomorphology 147
Lithology and Stratigraphy 148
Soil Taxa 148
Potential Natural Vegetation 148
Fauna 148
Climate 148
Surface Water Characteristics 148
Disturbance Regimes 149
Land Use 149
Blackland Prairies (Section 255B) 149
Geomorphology 149
Lithology and Stratigraphy 149
Soil Taxa 149
Potential Natural Vegetation 150
Fauna 150
Climate 150
Disturbance Regimes 150
Land Use 150
Oak Woods and Prairies (Section 255C) 150
Geomorphology 150
Lithology and Stratigraphy 151
Soil Taxa 151
Potential Natural Vegetation 151
Fauna 151
Climate 152
Surface Water Characteristics 152
Disturbance Regimes 152
Land Use 152
Central Gulf Prairies and Marshes (Section 255D) 152
Geomorphology 152
Lithology and Stratigraphy 153

Soil Taxa 153
Potential Natural Vegetation 153
Fauna 153
Climate 153
Surface Water Characteristics 153
Disturbance Regimes 154
Land Use 154

Great Plains Steppe and Shrub 154
Redbed Plains (Section 311A) 154
Geomorphology 154
Lithology and Stratigraphy 155
Soil Taxa 155
Potential Natural Vegetation 155
Fauna 155
Climate 155
Surface Water Characteristics 155
Disturbance Regimes 155
Land Use 155

Southwest Plateau and Plains Dry Steppe and Shrub 156
Texas High Plains (Section 315B) 156
Geomorphology 156
Lithology and Stratigraphy 156
Soil Taxa 156
Potential Natural Vegetation 156
Fauna 156
Climate 157
Surface Water Characteristics 157
Disturbance Regimes 157
Land Use 157
Rolling Plains (Section 315C) 158
Geomorphology 158
Lithology and Stratigraphy 158
Soil Taxa 158
Potential Natural Vegetation 159
Fauna 159
Climate 159
Surface Water Characteristics 159
Disturbance Regimes 159

Land Use 159
Edwards Plateau (Section 315D) 159
Geomorphology 159
Lithology and Stratigraphy 160
Soil Taxa 160
Potential Natural Vegetation 160
Fauna 160
Climate 161
Surface Water Characteristics 161
Disturbance Regimes 161
Land Use 161
Rio Grande Plain (Section 315E) 161
Geomorphology 161
Lithology and Stratigraphy 161
Soil Taxa 161
Potential Natural Vegetation 162
Fauna 162
Climate 163
Surface Water Characteristics 163
Disturbance Regimes 163
Land Use 163
Southern Gulf Prairies and Marshes (Section 315F) 163
Geomorphology 163
Lithology and Stratigraphy 164
Soil Taxa 164
Potential Natural Vegetation 164
Fauna 164
Climate 164
Surface Water Characteristics 164
Disturbance Regimes 165
Land Use 165

Arizona-New Mexico Mountains Semi-Desert - Open Woodland - Coniferous Forest - Alpine Meadow 165
Sacramento-Manzano Mountain (Section M313B) 165
Geomorphology 165
Lithology and Stratigraphy 165
Soil Taxa 166
Potential Natural Vegetation 166
Climate 166
Surface Water Characteristics 166

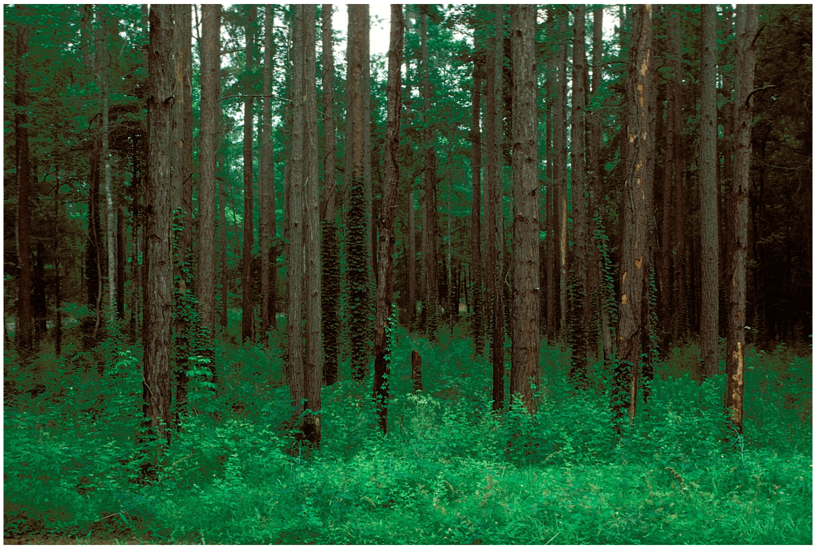
Disturbance Regimes 166
Cultural Ecology 166

Chihuahuan Semi-Desert 167
Basin and Range (Section 321A) 167
Geomorphology 167
Lithology and Stratigraphy 168
Soil Taxa 168
Potential Natural Vegetation 168
Climate 168
Surface Water Characteristics 168
Disturbance Regimes 169
Land Use 169
Cultural Ecology 169
Stockton Plateau (Section 321B) 169
Geomorphology 169
Lithology and Stratigraphy 170
Soil Taxa 170
Potential Natural Vegetation 170
Fauna 170
Climate 171
Surface Water Characteristics 171
Disturbance Regimes 171
Land Use 171

Great Plains-Palouse Dry Steppe 171
Southern High Plains (Section 331B) 171
Geomorphology 171
Lithology and Stratigraphy 172
Soil Taxa 172
Potential Natural Vegetation 172
Fauna 172
Climate 172
Surface Water Characteristics 172
Land Use 172

Southeastern Mixed Forest

Mid Coastal Plains, Western (Section 231E)



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Geomorphology. This Section is in the Coastal Plains geomorphic province. The predominant landform occupying about 80% of the Section consists of moderately dissected irregular plains of marine origin. The plains were formed by deposition of continental sediments onto submerged, shallow continental shelf, which was later exposed by sea level subsidence. Other landforms consist of plains with hills and smooth plains. Elevations range from 80 to 650 ft (25 to 200 m). Local relief ranges from 100 to 300 ft (30 to 90 m).

Lithology and Stratigraphy. Rock units formed during the Cenozoic Era. Strata consist of Tertiary marine deposits (glauconitic sands and clays with lenses of coquinid limestone; clay and silty clay).

Soil Taxa. Soils are predominantly Udults. Paleudults, Hapludults, Hapludalfs, Paleudalfs, and Albaqualfs are on uplands. Fluvaquents, Udifluvents, Eutrochrepts, and Glossaqualfs are on bottom lands along major streams. Soils have a thermic temperature regime, a udic moisture regime, and siliceous or mixed mineralogy. Most soils have formed from sandstone and shale parent materials. Soils are generally coarse textured, deep, and have adequate moisture for plant growth during the growing season.

Potential Natural Vegetation. Kuchler mapped this area as oak-hickory-pine forest, southern mixed forest, and southern floodplain forest. The predominant vegetation form consists of needle-leaved evergreen trees. Belts of cold deciduous, broad-leaved hardwoods are prevalent along rivers. The principal forest cover type is loblolly and longleaf pines. Where hardwoods are prevalent, species consist of post, white, blackjack, and southern red oaks. Species of bottom lands are red maple, green ash, Nuttall oak, sweetgum, and swamp hickory.

Fauna. The elk, mountain lion, wolf, Carolina parakeet, and ivory-billed woodpecker once inhabited this Section. Presently, the fauna include white-tailed deer, black bear, bobcat, gray fox, raccoon, cottontail rabbit, gray squirrel, fox squirrel, striped skunk, swamp rabbit, and many small rodents and shrews. The turkey, bobwhite, and mourning dove are game birds in various parts of this Section. In flooded areas, ibises, cormorants, herons, egrets, and kingfishers are common. Songbirds include the red-eyed vireo, cardinal, tufted titmouse, wood thrush, summer tanager, blue-gray gnatcatcher, hooded warbler, and Carolina wren. The herpetofauna include the box turtle, common garter snake, and timber rattlesnake.

Climate. Annual precipitation averages 40 to 54 inches (1,000 to 1,300 mm). Temperature averages 61 to 68 F (16 to 20 C°). The growing season lasts about 200 to 270 days.

Surface Water Characteristics. There is a moderate density of small to medium size perennial streams and associated rivers, most with moderate volume of water flowing at low velocity. Dendritic drainage pattern has developed. Major rivers draining this Section include the Red and Ouachita.

Disturbance Regimes. Fire has probably been the principal historical disturbance. Climatic influences include occasional summer droughts and winter ice storms, and infrequent hurricanes. Insect disturbances are often caused by southern pine beetles.

Land Use. Natural vegetation has been cleared for agriculture on about 25% of the area. Much of the non-cleared land is managed for forestry.

Eastern Gulf Prairies and Marshes (Section 231F)

Geomorphology. This Section is in the Coastal Plains geomorphic province. The predominant landform is a flat, weakly dissected alluvial plain formed by deposition of continental sediments onto submerged, shallow continental shelf, which was later exposed by sea level subsidence. Along the coast, fluvial deposition and shore zone processes are active in developing and maintaining beaches, swamps, and mud flats. Elevation ranges from 10 to 330 ft (3 to 100 m). Local relief ranges from 0 to 100 ft (0 to 30 m).

Lithology and Stratigraphy. Rock units formed during the Cenozoic Era. Strata consist of Quaternary marine deposits (non-glacial sand, silt, and clay deposits of upland origin).

Soil Taxa. Aquolls, Saprists, Aquents, and Hemists are the principal soils along the coast. Also along the coast are Aquolls, Haplaquolls, Medisaprists, Hydraquents, and Medihemists, all of which are poorly drained and subject to flooding and high water tables. These soils have a thermic temperature regime and an aquic moisture regime. Farther inland, Uderts and Aqualfs are the main soils, especially where saline prairie vegetation is present. Soils farther inland on low lands are Pelluderts, Pellusterts, Albaqualfs, Ochraqualfs, and Glossaqualfs. Situated on flood plains are Argiaquolls, Haplaquolls, and Haplaquepts. Soils have a thermic to hyperthermic moisture regime, and an aquic moisture regime. These soils are deep, clayey, poorly drained, and have subsoils that are slowly permeable.

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Potential Natural Vegetation. Kuchler classified vegetation as bluestem-sacahuista prairie and southern cordgrass prairie. Predominant vegetation is mid to tall grass grasslands. Species consist of little bluestem, indiangrass, switchgrass, and big bluestem. Occasional areas of live oak are present. Poorly drained areas along the coast support freshwater and saltwater marsh vegetation of sedges, rushes, saltgrass, and cordgrass.

Fauna. Typical large herbivores and carnivores include manatee, coyote, red wolf, ringtail, ocelots, and river otter. Smaller herbivores include swamp rabbit, fulvous harvest mouse, eastern wood rat, and nutria. Common birds of freshwater marshes, lakes, ponds, and rivers include reddish egret, white-faced ibis, white-fronted goose, and olivaceous cormorant. Attwater's prairie chicken was once common in the grasslands. Reptiles and amphibians include American alligator, Gulf coast salt marsh snake, Gulf coast toad and pig frog, diamondback terrapin, Mediterranean gecko, and the Texas horned lizard.

Climate. Average annual precipitation is from 30 to 55 inches (750 to 1,400 mm). Temperature averages 66 to 74 F (19 to 23 C°). The growing season lasts 250 to 330 days.

Surface Water Characteristics. There is a moderate density of small to medium size perennial streams and very low density of associated rivers; most have a moderate volume of water at very low velocity. Water table is high in many areas, resulting in poor natural drainage and abundance of wetlands. Poorly defined drainage pattern has developed on this very young, weakly dissected plain. Abundance of palustrine systems having seasonally high water level. This Section adjoins the Louisianian Marine and Estuarine Province delineated by the USDI FWS.

Disturbance Regimes. Fire and ocean tides have likely been the principal historical disturbance. Climatic influences include occasional hurricanes.

Land Use. Natural vegetation has been cleared for agricultural crops on about 40% of the area.

Outer Coastal Plain Mixed Forest

Louisiana Coast Prairies and Marshes (Section 232E)

Geomorphology. This Section is in the Coastal Plains geomorphic Province. The predominant landform is a flat, weakly dissected alluvial plain formed by deposition of continental sediments onto submerged, shallow continental shelf, which was later exposed by sea level subsidence. Along the coast, fluvial deposition and shore zone processes are active in developing and maintaining beaches, swamps, and mud flats. Elevation ranges from 0 to 160 ft (0 to 50 m). Local relief ranges from 0 to 50 ft (0 to 15 m).

Photo courtesy Texas Parks and Wildlife Dept. ©2003

Lithology and Stratigraphy. Rock units formed during the Cenozoic Era. Strata consist of Quaternary marine deposits of terrestrial origin, non glacial sand, silt, and clay.

Soil Taxa. Aquolls, Saprists, Aquents, and Hemists are the principal soils along the coast. Also along the coast are Aquolls, Haplaquolls, Medisaprists, Hydraquents, and Medihemists, all of which are poorly drained and subject to flooding and high water tables. These soils have a thermic temperature regime and an aquic moisture regime.

Potential Natural Vegetation. Kuchler classified vegetation as bluestem-sacahuista prairie and southern cordgrass prairie. Much of the existing vegetation is nonforested grasslands. Prairie grasslands dominate areas inland from the coast and consist of little bluestem, indiangrass, switchgrass, and big bluestem. Occasional areas of live oak are present. Poorly drained areas along the coast support freshwater and saltwater marsh vegetation of sedges, rushes, saltgrass, and cordgrass.

Fauna. Large herbivores and carnivores include manatee, coyote, red wolf, ringtail, and river otter. Ocelots were once common, but are now rare. Smaller herbivores include swamp rabbit, fulvous harvest mouse, eastern wood rat, and nutria. Birds of fresh water marshes, lakes, ponds, and rivers include reddish egret, white-faced ibis, white-fronted goose, and olivaceous cormorant. Birds of grasslands include Attwater's prairie chicken. Reptiles and amphibians include the Gulf coast salt marsh snake, Gulf coast toad, pig frog, American Alligator, diamondback terrapin, Mediterranean gecko, and Texas horned lizard.

Climate. Annual precipitation averages 25 to 55 inches (620 to 1,400 mm). Temperature averages 68 to 70 F (20 to 21 C°). The growing season lasts 280 to 320 days.

Surface Water Characteristics. There is a moderate density of small to medium size perennial streams and very low density of associated rivers, most with moderate volume of water at very low velocity. Water table is high in many areas, resulting in poor natural drainage and an abundance of wetlands. The Mississippi River flows through this Section into the Gulf of Mexico. Palustrine systems are abundant and have seasonally high water levels. This Section adjoins the Louisianian Marine and Estuarine Province delineated by the USDI FWS.

Disturbance Regimes. Fire and ocean tides have probably been the principal historical disturbance. Climatic influences include occasional hurricanes.

Land Use. Natural vegetation has been converted to agricultural crops on about 40% of the area.

Coastal Plains and Flatwoods, Western Gulf (Section 232F)

Photo courtesy Texas Parks and Wildlife Dept. ©2003

Geomorphology. This Section is in the Coastal Plains geomorphic province. The predominant landform consists of weakly to moderately dissected irregular plains of alluvial origin formed by deposition of continental sediments onto a submerged, shallow continental shelf, which was later exposed by sea level subsidence. Along the coast, fluvial deposition and shore zone processes are active in developing and maintaining beaches, swamps, and mud flats. About 80% of this Section consists of irregular plains. Other landforms include flat plains and plains with hills. Elevation ranges from 80 to 660 ft (25 to 200 m). Local relief mostly ranges from 100 to 300 ft

(30 to 90 m) on irregular plains; however, relief ranges from 0 to 100 ft (0 to 30 m) on flat plains and 300 to 500 ft (90 to 150 m) where plains with hills are present.

Lithology and Stratigraphy. Rocks in this Section formed during the Cenozoic Era. About 80% of the geologic strata consist of Tertiary marine deposits, including glauconitic, calcareous, and fossiliferous strata with lignitic sandy and argillaceous contents. Quaternary marine deposits are present along the Red River.

Soil Taxa. Soils are mostly Udults. Paleudults, Hapludults, Hapludalfs, Paleudalfs, and Albaqualfs are on uplands. Fluvaquents, Udifluvents, Eutrochrepts, and Glossaqualfs are along major streams. Soils are mostly derived from weathered sandstone and shale. Soils have a thermic temperature regime, a udic moisture regime, and siliceous or mixed mineralogy. Soils are deep, coarsely textured, mostly well drained, and have an adequate supply of moisture for use by vegetation during the growing season.

Potential Natural Vegetation. Kuchler mapped vegetation as southern mixed forest, oak-hickory-pine forest, and southern flood plain forest. The predominant vegetation form is evergreen needle-leaved forest with a small area of cold-deciduous alluvial forest. The slash pine and longleaf pine cover type dominates most of the Section. The loblolly pine-shortleaf pine cover type is common in the northern parts of the Section. A bottomland type is prevalent along most major rivers and consists of cottonwood, sycamore, sugarberry, hackberry, silver maple, and red maple.

Fauna. The elk, mountain lion, wolf, Carolina parakeet, and ivory-billed woodpecker once inhabited this Section. The endangered Florida panther may be encountered rarely. Presently, the fauna include white-tailed deer, black bear, bobcat, gray fox, raccoon, cottontail rabbit, gray squirrel, fox squirrel, striped skunk, swamp rabbit, and many small rodents and shrews. The presence of turkey, bobwhite, and mourning dove is widespread. Resident and migratory nongame bird species are numerous, as are species of migratory waterfowl. In flooded areas, ibises, cormorants, herons, egrets, and kingfishers are common. Songbirds include the red-eyed vireo, cardinal, tufted titmouse, wood thrush, summer tanager, blue-gray gnatcatcher, hooded warbler, and Carolina wren. The endangered red-cockaded woodpecker and bald eagle inhabit this Section. The herpetofauna include the box turtle, common garter snake, eastern diamondback rattlesnake, timber rattlesnake, and American alligator.

Climate. Precipitation averages 40 to 54 inches (1,020 to 1,350 mm) annually. Annual temperature averages 61 to 68 F (16 to 20 C°). The growing season lasts 200 to 270 days.

Surface Water Characteristics. This Section has a moderate density of small to medium size perennial streams and associated rivers. Dendritic drainage pattern has developed without bedrock structural control. Major rivers include the Sabine, Red, and Mississippi.

Disturbance Regimes. Fire has probably been the principal historical disturbance. Climatic influences include occasional summer droughts and winter ice storms and infrequent hurricanes. Insect disturbances are often caused by southern pine beetles.

Land Use. Natural vegetation has been cleared for agriculture on about 60% of the area.

Prairie Parkland (Subtropical)

Cross Timbers and Prairies (Section 255A)

Photo courtesy Texas Parks and Wildlife Dept. ©2003

Geomorphology. This Section is in the Central Lowlands geomorphic province. The predominant landform on about 70% of the Section consists of irregular plains that originated from uplift of level bedded continental sediments, that had been deposited into a shallow inland sea, followed by a long period of erosion. Other landforms include plains with hills and open high hills. Elevation ranges from 330 to 1,300 ft (100 to 400 m). Local relief ranges from 100 to 300 ft (30 to 90 m).

Lithology and Stratigraphy. Rock units were formed during the Paleozoic (30%) and Mesozoic (70%) Eras. Paleozoic strata consist of Pennsylvanian marine deposits (sandstone, shale, coal, and limestone). Mesozoic strata consist of Lower Cretaceous marine deposits (limestone).

Soil Taxa. Soils in the Cross Timbers region are mainly Ustalfs. Paleustalfs and Haplustalfs are on uplands. Ustifluvents and Haplustolls are on narrow flood plains. Soils have a thermic temperature regime, a ustic moisture regime, and mixed or siliceous mineralogy. Soils are deep, well drained, and moderate textured; moisture is limited for use by vegetation during part of the growing season. Soils in the Prairie region are Ustolls, Userts, and Ochrepts. Pellusterts and Chromusterts are on upland valleys. Calciustolls are on smooth uplands. Haplustolls, Calciustolls, and Argiustolls are on areas of limestone parent material. Ustochrepts and Calciustolls occur on steep plateau sideslopes. Haplustolls are on flood plains. Argiustolls and Haplustalfs are on smooth uplands in northern areas of the Section. Soil temperature regime is thermic, moisture regime is ustic, and mineralogy is montmorillonitic, mixed, or carbonatic. Generally, soils are deep, fine textured, and well drained; moisture is limited for use by vegetation during parts of the growing season.

Potential Natural Vegetation. Kuchler classified vegetation as cross timbers *(Quercus-Andropogon*), oak-hickory forest, and oak-hickory-pine forest. The predominant vegetation form is cold-deciduous broad-leaved forest and extensive areas of tall grassland with a tree layer. Forest cover consists of post, live, and blackjack oaks, and pignut and mockernut hickories. Grasses consist of big and little bluestems, indiangrass, and sunflower.

Fauna. Among the fauna in this Section are white-tailed deer, black bear, bobcat, gray fox, raccoon, cottontail rabbit, gray squirrel, fox squirrel, eastern chipmunk, white-footed mouse, pine vole, short-tailed shrew, and cotton mouse. The turkey, bobwhite, and mourning dove are game birds in various parts of this Section. Songbirds include the red-eyed vireo, cardinal, tufted titmouse, wood thrush, summer tanager, blue-gray gnatcatcher, hooded warbler, and Carolina wren. The herpetofauna include the box turtle, common garter snake and timber rattlesnake.

Climate. Precipitation averages 35 to 40 inches (900 to 1,050 mm). About 5 to 18 inches (120 to 450 mm) of snow falls annually. Temperature averages 55 to 63 F (13 to 17 C°). The growing season lasts 190 to 235 days.

Surface Water Characteristics. This Section has a low to moderate density of perennial streams and associated rivers, mostly with low to moderate rates of flow and moderate velocity. Dendritic drainage patterns have developed. One of the major rivers draining this Section is the Red River. A relatively large number of water reservoirs have been constructed.

Disturbance Regimes. Fire and drought have probably been the principal historical sources of disturbance.

Land Use. Natural vegetation has been cleared for agricultural crops on about 75% of the area.

Blackland Prairies (Section 255B)

Photo courtesy Texas Parks and Wildlife Dept. ©2003

Geomorphology. This Section is in the Coastal Plains geomorphic province. The predominant landform is irregular plains. This Section is an elevated sea bottom that has been shaped by marine and shore-zone processes resulting from repeated episodes of submergence and emergence of the land from the ocean. Some geomorphic processes currently active throughout the area are gentle gradient valley stream erosion, transport and deposition. Elevation ranges from 330 to 660 ft (100 to 200 m). Local relief ranges from 100 to 300 ft.

Lithology and Stratigraphy. Rock units in this Section formed during the Mesozoic (10%) and Cenozoic (90%) Eras. Mesozoic strata consist of Upper Cretaceous marine deposits (shales, marls, and chalks). Cenozoic strata consists of Tertiary marine deposits.

Soil Taxa. Soils are Usterts, Ustolls, Aqualfs, and Ustalfs. Pellusterts are in upland valleys. Chromusterts are on eroded uplands. Haplustrolls and Ustorthents are along an Austin chalk escarpment. Calciustolls and Haplustolls are along stream terraces. Albaqualfs, Ochraqualfs, and Paleustalfs are on uplands. Pelluderts, Haplaquolls, and Chromusterts are on flood plains.

These soils have a thermic temperature regime, a ustic or aquic moisture regime, and montmorillonitic or mixed mineralogy. Generally, soils are deep, mostly well drained, medium to fine textured, and have limited soil moisture supplies for use by vegetation during parts of the growing season.

Potential Natural Vegetation. Kuchler mapped vegetation as blackland prairie (*Andropogon-Stipa*) and juniper-oak savanna. The predominant vegetation form is tall grassland consisting mainly of bunch grasses, such as indiangrass, big bluestem, switchgrass, and eastern gamagrass. A savanna community occurs along many major rivers, consisting of elm, pecan, cottonwood, and hackberry, with grasses between the trees.

Fauna. Faunal communities are characterized by species associated with a prairie climate and vegetation. Typical large herbivores and carnivores include coyote, ringtail, and collared peccary. Smaller herbivores include plains pocket gopher, fulvous harvest mouse, and northern pygmy mouse. Ocelots were once common, but are now rare. The bison is historically associated with the Section. Birds are typical of grass and shrublands; residents include many common species, such as turkey vulture, hairy woodpecker, cardinal, and yellow warbler. Smith's longspur, a bird of the Arctic tundra, winters here. Amphibians and reptiles typical of this area include eastern spadefoot toad, Great Plains narrow-mouthed frog, green toad, Texas toad, Gulf Coast toad, yellow mud turtle, Texas horned lizard, Texas spiny lizard, and Texas blind snake.

Climate. Precipitation ranges from 30 to 45 inches (750 to 1,150 mm), occurring mainly in spring from April through May. Temperature averages 63 to 70 F (17 to 21 C°). The growing season lasts 230 to 280 days.

Disturbance Regimes. Fire and drought have probably been the principal historical sources of disturbance.

Land Use. Natural vegetation has been changed to agricultural crops on about 75% of the area.

Oak Woods and Prairies (Section 255C)

Geomorphology. This Section is in the Coastal Plains geomorphic province. The predominant landform on about 80% of the Section consists of irregular plains. Other landforms include plains with hills and smooth plains. This Section is an elevated sea bottom that has been shaped by marine and shore-zone processes resulting from repeated episodes of submergence and emergence of the land from the ocean. Some geomorphic processes currently active throughout the area are gentle gradient valley stream erosion, transport and deposition. Elevation ranges from 650 to 1,310 ft (200 to 400 m). Local relief ranges from 100 to 300 ft.

Photo courtesy Texas Parks and Wildlife Dept. ©2003

Lithology and Stratigraphy. Rocks units formed during the Cenozoic Era. Strata are Tertiary marine sediments consisting of glauconitic, calcarious, fossiliferous strata with lignitic sandy and argillaceous deposits.

Soil Taxa. Soils are mostly Ustalfs. Paleustalfs and Albaqualfs are on uplands and other areas with thick sandy surface. Pelluderts, Pellusterts, and Hapludolls are on flood plains and clayey terraces along major rivers. These soils have a thermic temperature regime, an ustic moisture regime, and montmorillonitic mineralogy. Soils are deep, medium textured, and generally have a slowly permeable, clayey subsoil. Moisture may be limiting for plant growth during parts of the year.

Potential Natural Vegetation. Kuchler classified vegetation as oak-hickory forest, cross timbers (*Quercus-Andropogon*), and juniper-oak savanna. The predominant vegetation type is cold-deciduous, broad-leaved forest. The oak-hickory cover type consists of scarlet, post, and blackjack oaks, and pignut and mockernut hickories. Forests of elm, pecan, and walnut are in bottomlands. Little bluestem is the dominant grass.

Fauna. Faunal communities are characterized by species associated with a temperate, subhumid, forested environment. Common large herbivores and carnivores include coyote, ringtail, ocelot, and collared peccary. Smaller herbivores include plains pocket gopher, fulvous harvest mouse, northern pygmy mouse, southern short-tailed shrew, and least shrew. Jaguar and bison are historically associated with this Section. Birds typical of this Section include many wide-spread species, such as eastern bluebird, eastern meadowlark, grasshopper sparrow, mourning dove, Cooper's hawk, and mockingbird. Amphibians and reptiles include eastern spadefoot toad, Great Plains narrow-mouthed frog, green toad, yellow mud turtle, Texas horned lizard, Texas spiny lizard, and Texas blind snake.

Climate. Annual precipitation ranges from 27 to 40 inches (700 to 1,000 mm). Temperature ranges from 63 to 70 F (17 to 21 C°). The growing season lasts 200 to 260 days.

Surface Water Characteristics. There is a low density of small to medium size perennial streams and associated rivers, most with moderate volume of water flowing at low velocity. A major river draining this Section is the Trinity.

Disturbance Regimes. Fire and drought have probably been the principal historical disturbances.

Land Use. Natural vegetation has been converted to agricultural crops on about 75% of the area.

Central Gulf Prairies and Marshes (Section 255D)

Photo courtesy Texas Parks and Wildlife Dept. ©2003

Geomorphology. This Section is in the Coastal Plains geomorphic province. The predominant landform consists of a flat, weakly dissected alluvial plain formed by deposition of continental sediments onto a submerged, shallow continental shelf, which was later exposed by sea level subsidence. Along the coast, fluvial deposition and shore-zone processes are active in developing and maintaining beaches, swamps, and mud flats. Elevation ranges from sea level to 160 ft (0 to 50 m). Local relief ranges from 0 to 100 ft.

Lithology and Stratigraphy. Rock units formed during the Cenozoic Era. Strata consist of Quaternary marine deposits (non-glacial sand, silt, and clay deposits) of continental origin.

Soil Taxa. Soils are Aquents, Aqualfs, Aquolls, and Aquepts. Psammaquents, Udipsamments, Fluvaquents, and Salorthids are on barrier islands and long bays. Haplaquolls, Natraqualfs, Pelluderts, and Pellusterts are on low coastal terraces. Ochraqualfs, Albaqualfs, and Paleudalfs are found on plains. Haplaquolls, Haplaquents, and Fluvaquents are on coastal flats and flood plains. These soils have a hyperthermic and thermic temperature regime, an aquic moisture regime, and montmorillonitic, mixed, or siliceous mineralogy. Soils are fine to coarse textured, saline, and mostly poorly drained with high water tables.

Potential Natural Vegetation. Kuchler classified vegetation as bluestem-sacahuista prairie and southern cordgrass prairie. The predominant vegetation form is tall grassland consisting mainly of bunch grasses. Prairie grasslands dominate areas inland from the coast and consist of little bluestem, indiangrass, switchgrass, and big bluestem. Occasional areas of live oak are present. Poorly drained areas along the coast support freshwater and saltwater marsh vegetation of sedges, rushes, saltgrass, and cordgrass.

Fauna. Large to medium size herbivores and carnivores include coyote, ringtail, hog-nosed skunk, river otter, ocelot, and collared peccary. Smaller herbivores include swamp rabbit, plains pocket gopher, fulvous harvest mouse, northern pygmy mouse, and nutria. Bison and jaguar are historically associated with this Section. Birds of fresh water marshes, lakes, ponds, and rivers include reddish egret, white-faced egret, white-fronted goose, and olivaceous cormorant. Birds of these grassland include white-tailed hawk, bronzed cowbird, and Attwater's prairie chicken. The rare whooping crane winters in this Section at the Aransas National Wildlife Refuge. Reptiles include American alligator, Gulf coast salt marsh snake, Mediterranean gecko, keeled earless lizard, Texas horned lizard, Texas spiny lizard, and Texas blind snake. Amphibians common to this Section include Gulf coast toad and diamondback terrapin.

Climate. Annual precipitation ranges from 25 to 55 inches (620 to 1,400 mm). Temperature averages 68 to 70 F (20 to 21 C°). The growing season lasts 280 to 320 days.

Surface Water Characteristics. There is a moderate density of small to medium size perennial streams and a low density of associated rivers, most with moderate volume of water flowing at very low velocity. The water table is high in many areas, resulting in poor natural drainage and abundance of wetlands. A poorly defined drainage pattern has developed on very young plains.

An abundance of palustrine systems are present, having seasonally high water level. This Section adjoins the Carolinian and Louisianian Marine and Estuarine Provinces.

Disturbance Regimes. Ocean tides have probably been the principal historical disturbance. Climatic influences include occasional hurricanes.

Land Use. Natural vegetation has been converted to agricultural crops on about 40% of the area.

Great Plains Steppe and Shrub

Redbed Plains (Section 311A)

Geomorphology. This Section is in the Central Lowlands geomorphic province. Platform uplift of continental sediments deposited previously into a shallow inland sea, followed by a long period of erosion; these processes resulted in a moderately to strongly dissected region. About 70% of this Section consists of irregular plains. Other landforms include about equal areas of plains with low mountains, smooth plains, and tablelands. Elevation ranges from 1,600 to 3,000 ft (500 to 900 m). Local relief in much of the Section ranges from 100 to 300 ft (30 to 90 m). Smaller areas are present where relief ranges from 30 to 60 ft (10 to 20 m) in tablelands and up to 1,000 ft (300 m) in low mountains.

Photo courtesy Texas Parks and Wildlife Dept. ©2003

Lithology and Stratigraphy. Rocks formed during the Paleozoic Era. About 80% of the geologic strata consist of Permian marine deposits (sandstone, shale, and limestone). Other strata include Quaternary marine deposits and small isolated areas of Lower Cretaceous marine deposits (limestone).

Soil Taxa. Soils are Ustolls, Ustalfs, and Ochrepts. Most soils are on uplands and include Argiustolls, Paleustolls, Natrustolls, Haplustalfs, Paleustalfs, and Ustochrepts. Localized areas of Ustifluvents are on flood plains. These soils have a thermic temperature regime, a ustic moisture regime, and mixed mineralogy. Most soils are deep, well drained, variable in texture, and have limited moisture supplies for use by vegetation during part of the growing season.

Potential Natural Vegetation. Kuchler classified vegetation as bluestem-grama prairie, and cross timbers (*Quercus-Andropogon*); shinnery (*Quercus-Andropogon*); and sandsage-bluestem prairie. The predominant vegetation form is medium-tall grasslands with sparse tree cover. Grasses consist mainly of sand bluestem, little bluestem, and sand saltbrush.

Fauna. Representative large to medium size herbivores and carnivores include coyote, ringtail, and ocelot. Small herbivores include eastern cottontail, desert shrew, plains pocket mouse, Texas kangaroo rat, and prairie vole. Bison and black-footed ferret are historically associated with this Section. Common birds of thickets and grasslands include the roadrunner, bobwhite, barn owl, scissor-tailed flycatcher, and common crow. The golden-fronted woodpecker has a more restricted range. Amphibians common to this environment include Plains spadefoot toad, Great Plains narrow-mouthed frog, green toad, spotted chorus frog, and yellow-mud turtle. Typical reptiles include lesser earless lizard, Texas horned lizard, Prairie skink, and Texas blind snake.

Climate. Precipitation averages 20 to 30 inches (500 to 750 mm); snow averages 20 to 30 inches (500 to 750 mm) annually. Temperature averages 57 to 64 F (14 to 18 C°). The growing season lasts 185 to 230 days.

Surface Water Characteristics. The area has a low density of small to medium intermittent streams and associated rivers, most with a low volume of water flowing at low velocity. Dendritic drainage pattern has developed without bedrock structural control. Major rivers include the Washita, Canadian, and Red Rivers.

Disturbance Regimes. Fire and drought have probably been the principal historical disturbances.

Land Use. Natural vegetation has been converted to agricultural crops or pasture on about 90% of the area.

Southwest Plateau and Plains Dry Steppe and Shrub

Texas High Plains (Section 315B)

Geomorphology. This Section is in the Great Plains geomorphic province. The predominant landform consists of a broad, extensive flat plain formed by fluvial sedimentation of continental erosional products from adjacent mountain ranges, followed by sheet erosion and transport. These processes resulted in a region of moderate dissection. Elevation ranges from 2,600 to 6,500 ft (800 to 2,000 m). Local relief in most of the Section ranges from 100 to 300 ft, however, relief in the tablelands ranges from 300 to 500 ft.

Lithology and Stratigraphy. Rocks were formed during the Paleozoic (10%), Mesozoic (10%), and Cenozoic (80%) Eras. Paleozoic strata consist of Permian marine deposits (sandstone, shale, and limestone). Mesozoic strata consist of Triassic continental deposits (sandstone). Cenozoic strata consist of Tertiary Period deposits (poorly consolidated silt, sand, and gravel in varying proportions).

Soil Taxa. Soils are Ustolls and Ustalfs. Paleustolls, Argiustolls, Paleustalfs, and Haplustalfs are on uplands. Calciustolls, Haplustolls, and Paleustolls are on ridges and steeper slopes. Haplustolls occur on young valley floors. Pellusterts are in clayey playa-lake basins. Calciorthids, Paleorthids, and Torriorthents are on steep slopes in breaks. These soils have a mesic or thermic temperature regime, a ustic moisture regime, and mixed or carbonatic mineralogy. Soils are deep, fine to coarse textured, well drained, and have limited soil moisture for use by vegetation during parts of the growing season.

Potential Natural Vegetation. Kuchler classified vegetation as grama-buffalo grass and shinnery (*Quercus-Andropogon*). The predominant vegetation form is short grass communities composed of bunch grasses with a sparse shrub layer. Species include short grasses (blue gramma, and buffalograss), sagebrush, mesquite, and yucca.

Fauna. Typical large to medium size herbivores and carnivores include pronghorn, coyote, swift fox, ringtail, and ocelot. Typical smaller herbivores include desert shrew, desert cottontail, black-tailed prairie dog, yellow-faced pocket gopher, plains pocket mouse, silky pocket mouse, hispid pocket mouse, and white-throated woodrat. Bison are historically associated with this Section. Birds of grasslands include many species that typically occur over a wide area, such as roadrunner, house finch, yellow warbler, willow flycatcher, cedar waxwing, western kingbird, and golden eagle. The lesser prairie chicken, found here, is restricted to the more arid grasslands. Amphibians found in this Section include plains spadefoot toad, Couche's spadefoot toad, western spadefoot toad, plains leopard frog, Great Plains toad, green toad, red spotted toad, spotted chorus frog, and yellow-mud turtle. Reptiles include species such as Texas horned lizard, round-tailed horned lizard, Great Plains skink, Texas blind snake, and plains black-headed snake.

Photo courtesy Texas Parks and Wildlife Dept. ©2003

Climate. Precipitation averages 14 to 18 inches (350 to 450 mm), occurring mainly in the spring and fall. Temperature averages 55 to 63 F (13 to 17 C°). The growing season lasts 130 to 220 days.

Surface Water Characteristics. There is a low density of small intermittent streams and few associated rivers, all with low volume of water flowing at low velocity. A shallow dendritic drainage pattern has developed. Major rivers include the Canadian and Red. The Canadian River, in north Texas, is deeply incised into the Great Plains plateau and has developed a broad area (up to 50 miles wide) of complex topography locally known as "The Breaks." Playa lakes are common in the western part of this Section.

Disturbance Regimes. Fire and drought have probably been the principal historical disturbances.

Land Use. Natural vegetation has been converted to agricultural crops or pasture on about 90% of the area.

Rolling Plains (Section 315C)

Photo courtesy Texas Parks and Wildlife Dept. ©2003

Geomorphology. This Section is in the Central Lowlands geomorphic province. Landforms originated from platform uplift of continental sediments deposited previously into a shallow inland sea, followed by a long period of erosion. These processes resulted in a moderately dissected landscape. About 80% of this Section is equally divided between irregular plains and tablelands. Smaller areas of smooth plains and plains with hills are also present. Elevation ranges from 1,640 to 2,950 ft (500 to 900 m). Local relief in most of the Section ranges from 100 to 300 ft. Smaller areas are present where local relief ranges from 300 to 500 ft.

Lithology and Stratigraphy. Rocks were formed during the Paleozoic and Mesozoic Eras. Geologic strata consist of about equal amounts of Permian marine deposits and Triassic continental deposits (sandstone). A small area of Permian continental deposits (sandstone, shale, and limestone) is also present.

Soil Taxa. Soils are Ustolls, Ustalfs, and Ochrepts. Most soils are on uplands and include Argiustolls, Paleustolls, and Natrustolls, Haplustalfs, Paleustalfs, and Ustochrepts. Localized areas of Ustifluvents are on flood plains. These soils have a thermic temperature regime, a ustic moisture regime, and mixed mineralogy. Most soils are deep, well drained, variable in texture, and have limited moisture supplies for use by vegetation during part of the growing season.

Potential Natural Vegetation. Kuchler classified vegetation as mesquite-buffalo grass. The predominant vegetation form is medium-tall grassland with a sparse shrub cover. The vegetative community consists of sand and little bluestems and sagebrush.

Fauna. The faunal community consists of species suited to a semi-arid environment. Large to medium-size mammals include coyote, ringtail, ocelot, and collared peccary. Typical smaller herbivores include desert cottontail, hispid pocket mouse, Texas kangaroo rat, Texas mouse, desert shrew, and rock squirrel. Bison and black-footed ferret are historically associated with this Section. Domesticated cattle are the most common large herbivore. Birds of thickets and grasslands include black-capped vireo, Harris' sparrow, scaled quail, golden-fronted woodpecker, and pyrrhuloxia. Amphibians include Couche's spadefoot toad, Great Plains narrow-mouthed frog, green toad, red-spotted toad, and Texas toad. The spotted chorus frog, yellow-mud turtle, and Texas map turtle are in wetter areas. Common reptiles include lesser earless lizard, crevice spiny lizard, Texas spotted whiptail, Great Plains skink, prairie skink, four-lined skink, western hook-nosed snake, Harter's water snake, and plains black-headed snake.

Climate. Precipitation averages 18 to 24 inches (450 to 600 mm). Temperature averages 57 to 64 F (14 to 18 C°). The growing season lasts 185 to 230 days.

Surface Water Characteristics. There is a low density of small intermittent streams and few associated rivers, all with low volume of water flowing at low velocity. A dendritic drainage pattern has developed. Major rivers include the Colorado and Brazos.

Disturbance Regimes. Fire and drought have probably been the principal historical disturbances.

Land Use. Natural vegetation has been converted to agricultural crops or pasture on about 90% of the area.

Edwards Plateau (Section 315D)

Geomorphology. This Section is in the Great Plains geomorphic province. The predominant landform consists of a broad, extensive flat plain formed by fluvial sedimentation of continental erosional products from adjacent mountain ranges, followed by sheet erosion and transport; these processes resulted in a region of moderate dissection. About 90% of this Section consists of landforms equally divided between smooth plains and tablelands having moderate relief. Also included are smaller areas of open high hills, high hills, and plains with hills. Elevation ranges from 650 to 4,000 ft (200 to 1,200 m). Local relief in most of the Section ranges from 100 to 300 ft (30 to 90 m). In a small area of hills, relief ranges from 300 to 500 ft (90 to 150 m).

Photo courtesy Texas Parks and Wildlife Dept. ©2003

Lithology and Stratigraphy. Rock units in this Section were formed during the Precambrian (10%), Paleozoic (30%), and Mesozoic (60%) Eras. Precambrian strata consist of metamorphic rocks of paragneiss and schist structures and plutonic and intrusive rocks of granitic composition. Paleozoic strata consist of a mixture of Cambrian (carbonates) and lower Ordovician marine deposits (carbonates). Mesozoic strata consist of Cretaceous marine deposits (limestone and sandstone).

Soil Taxa. Soils are mostly Ustolls. Calciustolls are on limestone hills and plateaus. Chromusterts are on outwash plains and broad plateaus. Ustochrepts are on marl and chalk hills. Haplustolls are on stream deposits of valley floors. These soils have a thermic temperature regime, a ustic moisture regime, and carbonatic or montmorillonitic mineralogy. Soils are generally shallow, fine textured, and have limited soil moisture for use by vegetation during parts of the growing season.

Potential Natural Vegetation. Kuchler classified vegetation as juniper-oak savanna and mesquite-acacia-savanna. The predominant vegetation form is mid to short grasslands and evergreen scale-leaved woodlands with a sparse cover of drought-deciduous shrubs. A mixture of species may occur, including blackjack oak, red cedar, mesquite, live oak, and species of mid and short grass grasslands.

Fauna. Common large to medium size herbivores and carnivores include coyote, ringtail, coati, hog-nosed skunk, ocelot, and collared peccary. Smaller herbivores include Mexican ground squirrel, white-ankled mouse, and prairie vole. Bison are historically associated with this Section. Domesticated cattle are the most common large herbivores. Birds of thickets typically found here include scaled quail, golden-fronted woodpecker, golden-cheeked warbler, pyrrhuloxia, and long-billed thrasher. Amphibians include Couche's spadefoot toad, Rio Grande leopard frog, Great Plains narrow-mouthed frog, green toad, Texas toad, spotted chorus frog, barking frog, cliff chirping frog, and Texas map turtle. A number of salamanders in this Section have a very restricted range: San Marcas, Texas, Cormal blind, Valdina Farms, and Texas blind. Typical reptiles include Mediterranean gecko, spot-tailed earless lizard, keeled earless lizard, Texas spiny lizard, Great Plains skink, and four-lined skink.

Climate. Annual precipitation ranges from 15 to 30 inches (375 to 750 mm). Average temperature is 64 to 68 F (18 to 20 C°). The growing season lasts 230 to 270 days.

Surface Water Characteristics. A low density of small intermittent and occasional perennial streams occurs here. All generally have a low volume of water flowing at low velocity, except along the plateau escarpment, where flow rates can be high. A dendritic drainage pattern has developed. Major rivers include the Brazos and Colorado.

Disturbance Regimes. Fire and drought have probably been the principal historical disturbances.

Land Use. Natural vegetation has been changed to agricultural crops or pasture on about 90% of the area.

Rio Grande Plain (Section 315E)

Geomorphology. This Section is in the Coastal Plains geomorphic province. The predominant landform in this Section is a flat, weakly dissected alluvial plain formed by deposition of continental sediments onto submerged, shallow continental shelf, which was later exposed by sea level subsidence. Elevation ranges from 80 to 1,000 ft (25 to 300 m). Local relief in most of the Section ranges from 100 to 300 ft (30 to 90 m).

Lithology and Stratigraphy. Rocks formed during the Cenozoic Era. These strata consist of Tertiary marine deposits (glauconitic, calcareous, fossiliferous layers with lignitic sandy and argillaceous deposits).

Soil Taxa. Soils are Usterts, Torrerts, and Ustalfs. Pellusterts are on plains over clayey marine sediments. Paleustalfs are on eolian plains. Torrerts, Haplustolls, Calciustolls, Paleustalfs, and Haplustalfs are on plains. Calciustolls and Calciorthids are on plains over marine sediments.

Soils have a hyperthermic temperature regime, a ustic or aridic moisture regime, and mixed mineralogy. Soils are mostly deep, fine to coarse textured, well drained, and have limited soil moisture for use by vegetation during the growing season.

Potential Natural Vegetation. Kuchler classified vegetation as mesquite-acacia-savanna and ceniza shrub. The predominant vegetation form is short grassland with a sparse cover of drought deciduous shrubs. Species include mesquite, cactus, and tall and mid grasses. Live oaks and cottonwoods may be present along stream banks.

Photo courtesy Texas Parks and Wildlife Dept. ©2003

Fauna. Typical large to medium size herbivores and carnivores include coyote, ringtail, hog-nosed skunk, and ocelot. Smaller herbivores include Mexican ground squirrel, Texas pocket gopher, and southern plains woodrat. Bats typical of this Section include the ghost-faced and Sanborn's long-nosed. Bison, jaguar, and jaguarundi are historically associated with this Section. This Section and adjacent 315E form the northern range of a number of birds common to Mexico and South America. Typical birds include chachalaca, green kingfisher, pauraque, elf owl, white-winged dove, red-billed pigeon, black-headed oriole, kiskadee flycatcher, yellow-green vireo, Lichtenstein's oriole, tropical kingbird, beardless flycatcher, buff-bellied hummingbird, green jay, long-billed thrasher, and white-collared seedeater. Amphibians include Mexican burrowing toad, Rio Grande leopard frog, sheep frog, giant toad, spotted chorus frog, Mexican tree frog, Rio Grande chirping frog, and Berlandier's tortoise. Reptiles include Texas banded gecko, reticulate collared lizard, spot-tailed earless lizard, keeled earless lizard, blue spring lizard, mesquite lizard, rose-bellied lizard, Laredo striped whiptail, black-striped snake, indigo snake, speckled racer, and cat-eyed snake.

Climate. Precipitation ranges from 17 to 30 inches (420 to 750 mm), decreasing from east to west and occurring mostly during May and June. Temperature averages 70 to 72 F (21 to 22 C°). The growing season lasts 260 to 310 days.

Surface Water Characteristics. A sparse density of small to medium intermittent streams is present in a dendritic drainage pattern. Major rivers include the Rio Grande and Nueces.

Disturbance Regimes. Drought has probably been the principal historical disturbance.

Land Use. Natural vegetation has been converted to dry-land pasture for cattle grazing on about 90% of the area.

Southern Gulf Prairies and Marshes (Section 315F)

Photo courtesy Texas Parks and Wildlife Dept. ©2003

Geomorphology. This Section is in the Coastal Plains geomorphic province. The predominant landform consists of a flat, weakly dissected alluvial plain formed by deposition of continental sediments onto a submerged, shallow continental shelf, which was later exposed by sea level subsidence. Along the coast, fluvial deposition and shore-zone processes are active in developing and maintaining beaches, swamps, and mud flats. Elevation ranges from sea level to 160 ft (0 to 50 m). Local relief ranges from 0 to 50 ft (0 to 18 m).

Lithology and Stratigraphy. Rock units formed during the Cenozoic Era. These strata consist of Quaternary marine deposits of non-glacial sand, silt, and clay.

Soil Taxa. Soils are Aquents, Aqualfs, Aquolls, and Aquepts. Psammaquents, Udipsamments, Fluvaquents, and Salorthids are on barrier islands and long bays. Haplaquolls, Natraqualfs, Pelluderts, and Pellusterts are on low coastal terraces. Ochraqualfs, Albaqualfs, and Paleudalfs are found on plains. Haplaquolls, Haplaquents, and Fluvaquents are on coastal flats and flood plains. These soils have a hyperthermic and thermic temperature regime, an aquic moisture regime, and montmorillonitic, mixed, or siliceous mineralogy. Soils are fine to coarse textured, saline, and mostly poorly drained with high water tables.

Potential Natural Vegetation. Kuchler classified vegetation as bluestem-sacahuista prairie and southern cordgrass prairie. The predominant vegetation form is tall grassland with little tree cover. Grasslands dominate areas inland from the coast and consist of little bluestem, indiangrass, switchgrass, and big bluestem. Occasional areas of live oak are present. Poorly drained areas along the coast support freshwater and saltwater marsh vegetation of sedges, rushes, saltgrass, and cordgrass.

Fauna. The faunal communities typically include coyote, ringtail, hog-nosed skunk, ocelot, and collared peccary. Smaller mammals include Mexican ground squirrel, Texas pocket mouse, northern pygmy mouse, and southern Plains woodrat. Birds of freshwater marshes, lakes, ponds, and rivers include reddish egret, white-faced ibis, black-billed whistling duck, white-fronted goose, and olivaceous cormorant. Reptiles and amphibians include eastern spadefoot toad, Gulf coast toad, American alligator, diamondback terrapin, spiny-tailed iguana, Texas horned lizard, Texas spotted whiptail, and indigo snake.

Climate. Precipitation ranges from 25 to 55 inches (620 to 1,400 mm). Temperature averages 68 to 70 F (20 to 21 C°). The growing season lasts 280 to 320 days.

Surface Water Characteristics. A low density of small to medium perennial streams is present in this Section. The water table is high in many areas, resulting in poor natural drainage and abundance of wetlands. A poorly defined drainage pattern has developed on very young alluvial plains. There is an abundance of palustrine systems with seasonally high water levels. This Section adjoins the West Indian Marine and Estuarine Provinces.

Disturbance Regimes. Ocean tides and grazing have probably been the principal historical disturbance. Climatic influences include occasional hurricanes.

Land Use. Natural vegetation has been changed for agricultural crops on about 40% of the area.

Arizona-New Mexico Mountains Semi-Desert - Open Woodland - Coniferous Forest - Alpine Meadow

Sacramento-Manzano Mountain (Section M313B)

Geomorphology. This Section is in the Basin and Range physiographic province; it is located in central and south-central New Mexico. Major landforms are mountains, hills, plains, and scarps. Major landform features are the Sacramento, Manzano and Sandia Mountains and the Canadian Escarpment. Elevation ranges from 6,000 to 11,000 ft (2,130 to 3,690 m).

Photo courtesy Texas Parks and Wildlife Dept. ©2003

Lithology and Stratigraphy. There are Paleozoic sedimentary and Cenozoic aged igneous rocks and a few metamorphic rocks.

Soil Taxa. Soils include Eutroboralfs, Glossoboralfs, Dystrochrepts, Ustochrepts, Argiustolls, Calciustolls, Haplustolls, and Ustorthents with mesic and frigid temperature regimes and ustic and udic soil moisture regimes. A few Cryoboralfs and Cryochrepts occur with cryic soil temperature regimes and udic soil moisture regimes.

Potential Natural Vegetation. Vegetation consists of ponderosa pine in frigid soil temperature regimes and ustic and udic soil moisture regimes, Douglas-Fir in frigid-udic regimes, pinyon-juniper in mesic-ustic regimes, and Engelmann spruce, and subalpine fir in cryic-udic regimes. A few areas support grey oak at the lowest elevations.

Climate. Precipitation ranges from 12 to 35 inches (305 to 900 mm), with less than half of the precipitation falling during the winter. Temperature averages 40 to 57 F (4 to 8 C°); winter temperatures vary throughout this Section. The growing season lasts less than 70 to 170 days.

Surface Water Characteristics. This Section supplies much of the water to the Rio Grande and Pecos Valley basins. Several streams are perennial.

Disturbance Regimes. Natural fire regime averages 3 to 10 years of frequency in ponderosa pine forests. Much of this area is covered with timber, with some areas of commercial quality. Another use of land is as range.

Cultural Ecology. The earliest human occupation of the Sacramento-Manzano Mountain Section was characterized by an emphasis on big game hunting supplemented with gathering wild plant foods. Evidence for these activities is primarily restricted to the lower elevations and the base of the mountains. Around 6000 B.C., a gradual climate change from cooler and wetter to drier conditions resulted in a change of subsistence patterns. Highly mobile populations hunted and gathered a variety of resources throughout the region. The pinon-juniper zone was intensely exploited for both hunting and gathering. The mixed conifer forests were utilized to some extent for hunting and religious purposes, but the climate and scarcity of resources resulted in only sporadic use. As agriculture became important during the past 2000 years, most of the inhabitants became more sedentary and populations increased. Villages tended to be located close to water in the pinon-juniper woodland and lower alluvial fans at the base of the mountains. Athabascan groups entered the area sometime before the 1600's, utilizing many of the same resources; by the mid 1700's, Comanches occupied the plains immediately to the east. Today, Native Americans continue to use the mountains for gathering and ceremonial purposes.

The earliest historic settlement began in the late 1500's with the Spaniards. A few villages were established in the foothills of the Manzanos, Sandias, and near the headwaters of the Canadian and Pecos Rivers, but the Apaches kept most European settlers out of the Sacramentos and mountain ranges to the south. These settlers concentrated on the pinon-juniper woodlands and grasslands for hunting, fuel wood gathering, post cutting, and small subsistence farming. Beginning in the late 1800's, discoveries of gold and an increase in European settlement throughout the mountains resulted in more intensive use of the higher elevations for mining, logging, and ranching activities. Most of the homesteads and villages were located in the larger valleys or on the eastern slopes of the mountains near permanent water sources. By the turn of the century, logging dominated the activities in the mixed conifer zone, with ranching still playing an important role throughout the mountains. Currently, the area continues to consist primarily of small rural communities, with logging, fuel wood gathering, ranching, hunting, and recreation as the primary subsistence base. Anglo, Hispanic, and Mescalero Apache cultures are present. Recreational use has increased dramatically over the past few decades, particularly near the larger cities.

Chihuahuan Semi-Desert

Basin and Range (Section 321A)

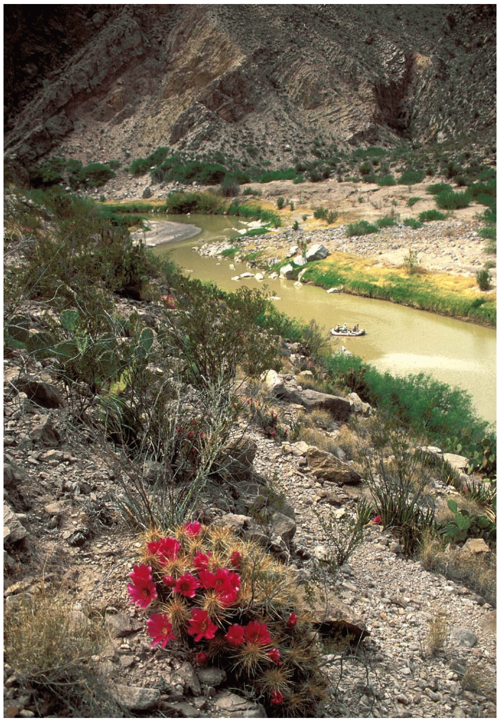

Photo courtesy Texas Parks and Wildlife Dept. ©2003

<u>Geomorphology</u>. This area, which is in the Basin and Range physiographic province, is located in southeast Arizona and southwest and central New Mexico. Relatively recent episodes of continental rifting, volcanism, erosion, and sedimentation have dominated this Section.

Oligocene faulting created the Rio Grande rift in New Mexico and west Texas and initiated volcanism. Subsequent Miocene composite volcanoes emitted silicic lava and ash. Along with Pliocene and Pliestocene mass wasting and cyclic erosion events, and associated with glacial cycles farther north, this combination of processes gradually filled the basins with deep sediments from adjacent mountain ranges. Current erosion cycles dissect these deposits and continue to modify the rift valley through transport and deposition processes. Various landforms comprise about equal areas: (1) plains with low mountains consisting of 50 to 80% of gently sloping area and local relief of 1,000 to 3,000 ft; (2) plains with high hills where relief is 1,000 to 3,000 ft; (3) open high hills with relief of 500 to 1,000 ft; and (4) tablelands with moderate relief averaging 100 to 300 ft. Elevation ranges from 2,600 to 5,500 ft (800 to 1676 m).

Lithology and Stratigraphy. Geologic strata consist of an undifferentiated mixture of Quaternary marine deposits, Miocene volcanic rocks, lower Tertiary volcanic rocks, and Lower Cretaceous marine deposits; Permian marine deposits of Ochoan and Guadalupian series; Paleocene continental deposits; Upper Cretaceous marine deposits; Precambrian plutonic and intrusive granitic rocks; Quarternary volcanic rocks; Permian continental deposits of Wolcampian age, and Miocene felsic volcanic rocks; upper Paleozoic marine deposits; Precambrian sedimentary rocks of Pahrump and Unkar groups; Precambrian Mazatal quartzite, Yavapai series, pinal schist, and metavolcanic formations.

Soil Taxa. Types are mostly Torriorthents with Calciorthids, Haplargids, and some Alfisols (10%) and Mollisols (10%) with a thermic temperature regime, an aridic moisture regime, and mixed or carbonatic mineralogy.

Potential Natural Vegetation. Kuchler mapped vegetation as trans-Pecos shrub savanna (*Flourensia-Larrea*); grama-tobosa desert grasslands; oak-juniper woodland; and mesquite-tarbush desert scrub.

Climate. Precipitation ranges from 8 to 13 inches (200 to 320 mm); it occurs mostly during July and August. Temperature ranges from 55 to 70 F (13 to 20 C°) and winters are mild. The growing season lasts 200 to 240 days.

Surface Water Characteristics. There is a low density of intermittent streams and very few associated rivers, most of which originate in distant mountainous areas. Flow rates are low to moderate, except during periods of heavy rain, when large amounts of surface runoff can occur. Dendritic drainage pattern has developed on dissected mountain slopes, largely without bedrock structural control. Playa lakes are common following periods of rains, but are ephemeral in the hot, dry climate prevalent in this Section.

Disturbance Regimes. Drought has probably been the principal historical source of disturbance.

Land Use. Land use includes range for cattle grazing on about 90% of the area.

Cultural Ecology. The Basin and Range Section is a physiographically diverse area characterized by expansive playas and open grassland basins cut by steep, rugged mountain, mesa, and canyon terrain. Humans have been utilizing the area for 8,000 to 10,000 years, although evidence of occupation prior to 7,000 B.C. remains scarce and scattered. Paleo-Indian materials are especially prevalent, however, from the foothills of the Tularosa Mountains. The area was widely utilized by Cochise and Oshara Tradition Archaic populations between 7,000 B.C. and 200 A.D. Site distribution points to a highly mobile hunting and gathering nomadic subsistence pattern initially, followed by use of increasingly smaller areas and a seasonal cycle of upland and lowland exploitation. Puebloan use and occupation were most prevalent between 200 and 1150 A.D. in the south and 200 and 1400 A.D. in the north. Southern basin, range, and mountain areas supported the Mogollon culture, while more northern mountain areas also included the southern fringe of the Anasazi tradition. Puebloan settlement reflected gradual movement toward major drainages and waterways over time. Basin and range deserts were widely used for wild plant procurement, agriculture, and settlement.

References to the Apache appear in 16th century Spanish documents and later historic accounts. Spanish expeditions passed through the area, but major settlements were restricted to the Rio Grande and the area east of the Mogollon and Tularosa Mountains. Livestock ranching and mining gained prominence in the 1800's. Gold, silver, copper, and turquoise were mined in the Mogollon, Burro, and Black Range Mountains of New Mexico. Introduction of the railroad in the 1800's witnessed an influx of European settlement along the Rio Grande, the southern Burro Mountains (Deming, Lordsburg, and Silver City, New Mexico) and more northern reaches of the Mogollon Mountains. In more northern, remote mountain areas, small ranching, mining, and timber-related settlements were established along major rivers and ephemeral drainages. Ranching and tourism flourish in the area today, and both Anglo and Hispanic cultures influence contemporary life.

Stockton Plateau (Section 321B)

Geomorphology. This Section is in the Great Plains geomorphic province. The predominant landform consists of open high hills with smaller areas of tablelands. These landform were formed by fluvial sedimentation of continental erosional products from adjacent mountain ranges, which was followed by sheet erosion and transport. These processes resulted in a region of shallow dissection. Elevation ranges from 2,600 to 4,500 ft (800 to 1,300 m). Local relief in most of the Section ranges from 500 to 1,000 ft. Relief in a small area of tablelands ranges from 300 to 500 ft.

Photo courtesy Texas Parks and Wildlife Dept. ©2003

Lithology and Stratigraphy. Rocks were formed during Paleozoic (35%), Mesozoic (40%), and Cenozoic (25%) Eras. Paleozoic strata consist of Pennsylvanian marine deposits. Mesozoic strata consist of nondifferentiated mixture of Lower and Upper Cretaceous marine deposits (limestone, and sandstone). Cenozoic strata consist of lower Tertiary volcanic rocks of high alkalic content.

Soil Taxa. Soils are Argids and Orthids. Haplargids, Paleargids, and Calciorthids are on uplands, piedmont plains, and dissected terraces. Calciorthids, Ustolls, and Torriorthents are on uplands with shallow depths to bedrock. Paleorthids are on mesas and terraces. Gypsiorthids are in closed basins. Natragids and Torrerts are on basin floors. Torrifluvents are on flood plains and Torripsamments are on sandy uplands. These soils have a thermic temperature regime, aridic moisture regime, and mixed or carbonatic mineralogy. Soils are well drained, shallow to deep, and medium textured. Soil moisture is limited for use by vegetation during most of the growing season.

Potential Natural Vegetation. Kuchler classified vegetation as trans-Pecos shrub savanna (*Flourensia-Larrea*); with juniper and red cedar woodlands. The predominant vegetation form is short to mid height grasslands with sparse cover of drought-deciduous and scale-leaved shrubs and small trees. Species include desert shrubs in association with short to mid height grasses and oak savannas.

Fauna. Typical large to medium size herbivores and carnivores include pronghorn, coyote, swift fox, ringtail, hooded skunk, ocelot, and collared peccary. Smaller herbivores include desert shrew, desert cottontail, Mexican ground squirrel, yellow-faced pocket gopher, Nelson's pocket mouse, and Merriam's kangaroo rat. Several bats, western mastiff and yuma myotis, are present here. Birds of grasslands include bronzed cowbird, Baird's sparrow, and white-necked raven.

Birds of thickets include black-capped vireo, scaled quail, Harris' hawk, Inca dove, cave swallow, golden-fronted woodpecker, and pyrrhuloxia. Amphibians include Couche's spadefoot toad, western spadefoot toad, Rio Grande leopard frog, Great Plains toad, red-spotted toad, spotted chirping frog, and Mexican mud turtle. Reptiles include Texas banded gecko, Big Bend gecko, desert spring lizard, canyon lizard, crevice spiny lizard, gray checkered whiptail, little striped whiptail, plateau spotted whiptail, checkered whiptail, Texas-Pecos rat snake, gray-banded kingsnake, Big Bend patch-nosed snake, Mexican black-nosed snake, Big Bend black-headed snake, rock rattlesnake, and black-tailed rattlesnake.

Climate. Precipitation ranges from 8 to 13 inches (200 to 320 mm). Temperature ranges from 55 to 64 F (13 to 18 C°). The growing season lasts 200 to 240 days.

Surface Water Characteristics. This section has a low density of intermittent streams that originate in nearby mountainous areas and flow mainly following rains. Major river systems include the Rio Grande and Big Canyon. Flow rates are low except during periods of heavy rain, when large amounts of surface runoff can occur. Dendritic drainage pattern has developed. Playa-type lakes are present following rains but quickly dry up, leaving high salt concentrations.

Disturbance Regimes. This section is part of the Chihuahuan Desert and drought has been the principal disturbance.

Land Use. Cattle grazing occurs on about 90% of the area.

Great Plains-Palouse Dry Steppe

Southern High Plains (Section 331B)

Geomorphology. This Section is in the Great Plains geomorphic province. The predominant landform is a broad, extensive flat plain formed by fluvial sedimentation of continental erosional products from adjacent mountain ranges, followed by sheet erosion and transport. These processes resulted in a region of moderate dissection. Landforms consist mostly of smooth plains with smaller areas of tablelands. Elevation ranges from 2,600 to 4,000 ft (800 to 1,200 m). Local relief ranges mainly from 100 to 300 ft (90 m). A small area of tablelands is present where relief ranges from 300 to 500 ft (90 to 150 m).

Lithology and Stratigraphy. Rocks were formed during the Paleozoic (20%), Mesozoic (20%), and Cenozoic (60%) Eras. Paleozoic strata consist of Permian marine deposits (shale and limestone). Mesozoic strata consists of Upper Cretaceous marine deposits (limestone and sandstone). Cenozoic strata consists of Quaternary continental deposits (poorly consolidated silt, sand, and gravel in varying proportions) and other localized marine deposits.

Soil Taxa. Soils are Ustolls and Ustalfs. Paleustolls, Argiustolls, Paleustalfs, and Haplustalfs are on uplands. Calciustolls, Haplustolls, and Paleustolls are on ridges and steeper slopes. Haplustolls occur on young valley floors. Pellusterts are in clayey playa lake basins. Calciorthids, Paleorthids, and Torriorthents are steep slopes in breaks. These soils have a mesic or thermic temperature regime, an ustic moisture regime, and mixed or carbonatic mineralogy. Soils are deep, fine to coarse textured, well drained, and have limited soil moisture for use by vegetation during parts of the growing season.

Potential Natural Vegetation. Kuchler classified vegetation as sandsage-bluestem prairie and bluestem-grama prairie. The predominant vegetation form is short to mid-height grasslands. Species composition includes bluegrama, buffalograss, hairy grama, and little bluestem.

Fauna. Large to medium size herbivores and carnivores typical of this Section include pronghorn, coyote, and ringtail. Smaller herbivores include desert shrew, black-tailed prairie dog, Plains pocket mouse, silky pocket mouse, and hispid pocket mouse. Bison and black-footed ferret are historically associated with this Section. Birds of grasslands include lesser prairie chicken, Swainson's hawk, and burrowing owl. Typical reptiles and amphibians include Great Plains toad, red spotted toad, lesser earless lizard, round-tailed horned lizard, Great Plains skink, and Plains black-headed snake.

Climate. Annual precipitation averages 16 to 20 inches (400 to 520 mm). Between 16 to 35 in (400 to 900 mm) of snow occurs. Temperature ranges from 50 to 57 F (10 to 14 C°). The growing season lasts 140 to 185 days.

Surface Water Characteristics. There is a low density of small intermittent streams with low volume of water flowing at low velocity. A dendritic drainage pattern has developed on a weakly dissected plateau, largely without bedrock structural control. Major rivers include the Cimarron and North Canadian.

Land Use. Natural vegetation has been converted to agricultural crops and range for cattle grazing on about 90% of the area.

APPENDIX B
Individual Sub-Layer Maps

Table of Contents

Chapter	Page
Diversity layer	176
Rarity layer	177
Sustainability layer	179

List of Figures

Figure	Page
Figure B1. Map of diversity sub-layer: appropriateness of land cover. This map is used to produce the map of the diversity layer (Figure 5).	181
Figure B2. Map of diversity sub-layer: contiguous size of undeveloped land. This map is used to produce the map of the diversity layer (Figure 5).	182
Figure B3. Map of diversity sub-layer: Shannon land cover diversity index. This map is used to produce the map of the diversity layer (Figure 5).	183
Figure B4. Map of diversity sub-layer: ecologically significant stream segments. This map is used to produce the map of the diversity layer (Figure 5).	184
Figure B5. Map of rarity sub-layer: vegetation rarity. This map is used to produce the map of the rarity layer (Figure 6).	185
Figure B6. Map of rarity sub-layer: natural heritage rank. This map is used to produce the map of the rarity layer (Figure 6).	186
Figure B7. Map of rarity sub-layer: taxonomic richness. This map is used to produce the map of the rarity layer (Figure 6).	187
Figure B8. Map of rarity sub-layer: rare species richness. This map is used to produce the map of the rarity layer (Figure 6).	188

Figure B9. Map of sustainability sub-layer: contiguous land cover type. This map is used to produce the map of the sustainability layer (Figure 6). 189

Figure B10. Map of sustainability sub-layer: regularity of ecosystem boundary. This map is used to produce the map of the sustainability layer (Figure 7). 190

Figure B11. Map of sustainability sub-layer: appropriateness of land cover. This map is used to produce the map of the sustainability layer (Figure 7). 191

Figure B12. Map of sustainability sub-layer: waterway obstruction. This map is used to produce the map of the sustainability layer (Figure 7). 192

Figure B13. Map of sustainability sub-layer: road density. This map is used to produce the map of the sustainability layer (Figure 7). 193

Figure B14. Map of sustainability sub-layer: airport noise. This map is used to produce the map of the sustainability layer (Figure 7). 194

Figure B15. Map of sustainability sub-layer: Superfund National Priority List and state Superfund Sites. This map is used to produce the map of the sustainability layer (Figure 7). 195

Figure B16. Map of sustainability sub-layer: water quality. This map is used to produce the map of the sustainability layer (Figure 7). 196

Figure B17. Map of sustainability sub-layer: air quality. This map is used to produce the map of the sustainability layer (Figure 7). 197

Figure B18. Map of sustainability sub-layer: RCRA TSD, corrective action and state VCP sites. This map is used to produce the map of the sustainability layer (Figure 7). 198

Figure B19. Map of sustainability sub-layer: urban/agriculture disturbance. This map is used to produce the map of the sustainability layer (Figure 7). 199

The figures displayed in this appendix represent the individual sub-layers that constitute the main layers and ultimately the composite. The data for each sub-layer was calculated at the ecoregion level. However, for GIS technical reasons and presentation purposes, the legends of Appendix B figures reflect statewide ranking (i.e., the red shaded areas indicate the particular range of values statewide). This is different from the report text where sub-layers were combined and the results presented by ecoregion (i.e., the red areas indicate the 1%, 10%, etc. in that particular ecoregion). The data is the same (i.e., all calculated by ecoregion), only the presentation legend and scaling is different. On some figures, there were enough cells with a score of 100 that there was no way to separate the top 1% and top 10% (the top 1% of cells scored 100 and the top 10% of cells also scored 100), for example, road density (Figure B13).

Diversity layer

The statewide trend shows a higher level of appropriate vegetation in Rio Grande Plain, Stockton Plateau, Chihuahuan Desert Basin and Range, the southern part of Rolling Plains ecoregion. The Mid Coastal Plains Western Section, Oak Woods and Prairies, and Coastal Prairies and Marshes ecoregions show more disturbance in terms of what type of vegetation cover would exist without human influence (Figure B1). The amount of potential natural vegetation is also related to the amount of human disturbance, i.e. issues concerning sustainability of the area (see Sustainability section below).

There are many areas of larger tracts of undeveloped land including Chihuahuan Desert Basin and Range and Stockton Plateau ecoregions, portions of the Rolling Plains ecoregion, Rio Grande Plain ecoregion, northern Texas High Plains ecoregion (around the Canadian River), southern portion of the Edwards Plateau, Mid Coastal Plains Western Section, and Coastal Plains and Flatwoods Western Gulf Section (Figure B2).

The Shannon land diversity index map shows higher levels in the Blackland Prairie, Oak Woods and Prairies, Mid Coastal Plains Western Section, and Coastal Plains and Flatwoods Western Gulf Section ecoregions which might seem contradictory to the previous measure of contiguous land cover. Figure B3 shows that there are more, different types of undeveloped land cover in the eastern part of the state, covering several ecoregions and not as many undeveloped land cover types (nor as well dispersed), in the northern and western portions of the state. For various ecological reasons, the central and eastern portions of the state maintain this vegetative stratification. The amount of water adds another dimension of diversity, in that wetland areas are present. Fewer wetland areas or vegetative stratification exists in the western and northern parts of Texas.

Ecologically significant stream segments (Figure B4) are ecologically unique areas determined by TPWD based on biological function, hydrologic function, riparian conservation areas, high water quality (including aquatic life and aesthetic value), and threatened or endangered species. Significant stream segments are fairly well distributed throughout the central and eastern portions of the state.

Rarity layer

Oak Woods and Prairies, and Central Gulf Prairies and Marshes ecoregions show the highest levels of vegetation rarity. The pattern of these rare areas is indicative of riparian areas (Figure B5). This is particularly evident in the Mid Coastal Plains Western Section, and the northern portion of the Oak Woods and Prairies ecoregion. In addition, the Central Gulf Prairies and Marshes ecoregion shows a high density of rare vegetation types.

The Rolling Plains, Cross Timbers and Prairie and Texas High Plains ecoregions have species with lower natural heritage ranks (Figure B6). Most of the areas that have high natural heritage ranks are located Chihuahuan Desert Basin and Range ecoregion, Edwards Plateau, southern Rio Grande Plain, Central Gulf Prairies and Marshes, and Southern Gulf Prairies and Marshes, ecoregions (Figure B6). The Rio Grande Plain along the border with Mexico constitutes the northernmost range of several subtropical species that exist principally in Mexico and Central America. The Big Bend area in the Chihuahuan Desert Basin and Range (due to diverse topography) and Edwards Plateau (due to karst features) are known as centers of high endemism.

There are several areas in Texas that show moderate and moderately high taxonomic richness, but only very few areas show the highest numbers of rare taxa (Figure B7). In particular, the Edwards Plateau is an area of high endemism due to the karst geologic features.

There are only very few areas that show the greatest number of rare species (or richness), including the Big Bend area of the Chihuahuan Desert Basin and Range ecoregion in west Texas, Sacramento-Manzano Mountains ecoregion (primarily the Guadalupe Mountains), Coastal Plains and Flatwoods Western Gulf Section, parts of the Edwards Aquifer and Rio Grande Plain scored in the highest percentage (i.e., most rare number of species) (Figure B8).

Sustainability layer

Calculation of contiguous land cover types shows that there are larger portions of these ecoregions with contiguous land cover types in the Rio Grande Plain, Chihuahuan Desert Basin and Range, Stockton Plateau, Edwards Plateau, northern portions of the Texas High Plains, and portions of the Rolling Plains (Figure B9). This may be due to larger unbroken tracts of a single land cover type (i.e., shrubland or desert community types) compared to other areas of the state. In the eastern half of the state, Blackland Prairie, Oak Woods and Prairie, and Mid Coastal Plain Western Section, there may be more different types of undeveloped land cover, but none are very large. These areas lack the connectivity of the west.

Figure B10 shows the locations where the perimeter-to-area ratio is small, and therefore ecological communities more sustainable. Land cover types with smaller PAR are scattered through the Rolling Plains, Cross Timbers and Prairie, Blackland Prairie, Oak Woods and Prairie, Mid Coastal Plain Western Section, Gulf Coast Prairies and Marshes, and Coastal Plains and Flatwoods Western Gulf Section. These areas are the top 1% with the smallest PAR and thus, more sustainable areas in Texas.

Areas that most closely match pre-settlement vegetation (Figure B11) and have been less disturbed by human activities are the Rio Grande Plain ecoregion, the Stockton Plateau, portions of the Edwards Plateau and Chihuahuan Desert Basin and Range ecoregions. The eastern portion of the state has been impacted more by human activity and the land cover types present do not reflect pre-settlement conditions (Kuchler 1964).

Portions of the Chihuahuan Desert Basin and Range, Stockton Plateau, Rio Grande Plain, Texas High Plains, and Coastal Plain and Flatwoods Western Gulf Section have the fewest number of dams per HUC and therefore are more sustainable (Figure B12). Cross Timbers and Prairies, Blackland Prairies, and Oak Woods and Prairies have areas in the top 25% most sustainable areas in terms of waterway obstructions.

Road density (Figure B13) reflects populated areas and the means to connect them throughout Texas. For example, IH35 connects Austin, San Antonio, and Dallas-Ft. Worth. Consequently, this transportation corridor is well-developed with side roads and urban activities.

Figure B14 shows the buffered locations of airports in Texas. Large population centers, such as Dallas-Ft Worth and Houston, where there may be multiple airports are evident.

Several Superfund NPL sites are located near high population areas, including Houston, San Antonio, and Dallas-Ft.Worth (Figure B15).

The bulk of impacted stream segments not meeting their designated use (CWA Section 303(d)) are in the eastern half of the state where the majority of the water in Texas occurs (Figure B16).

Areas of poor air quality are located near the major cities in Texas: Houston, San Antonio, Dallas, El Paso, and Midland-Odessa (Figure B17).

Most of the RCRA sites are located near the major population centers in Texas: Houston, Dallas-Ft Worth, Austin , and San Antonio (Figure B18).

The population centers and much of the agricultural activities are in the Blackland Prairies, Texas High Plains, and Oak Woods and Prairies ecoregions. Additional urban and agricultural activities are scattered throughout the Rolling Plains, Mid Coastal Plains Western Section, and portions of the South, Central, and Eastern Gulf Prairies and Marshes ecoregion (Figure B19).

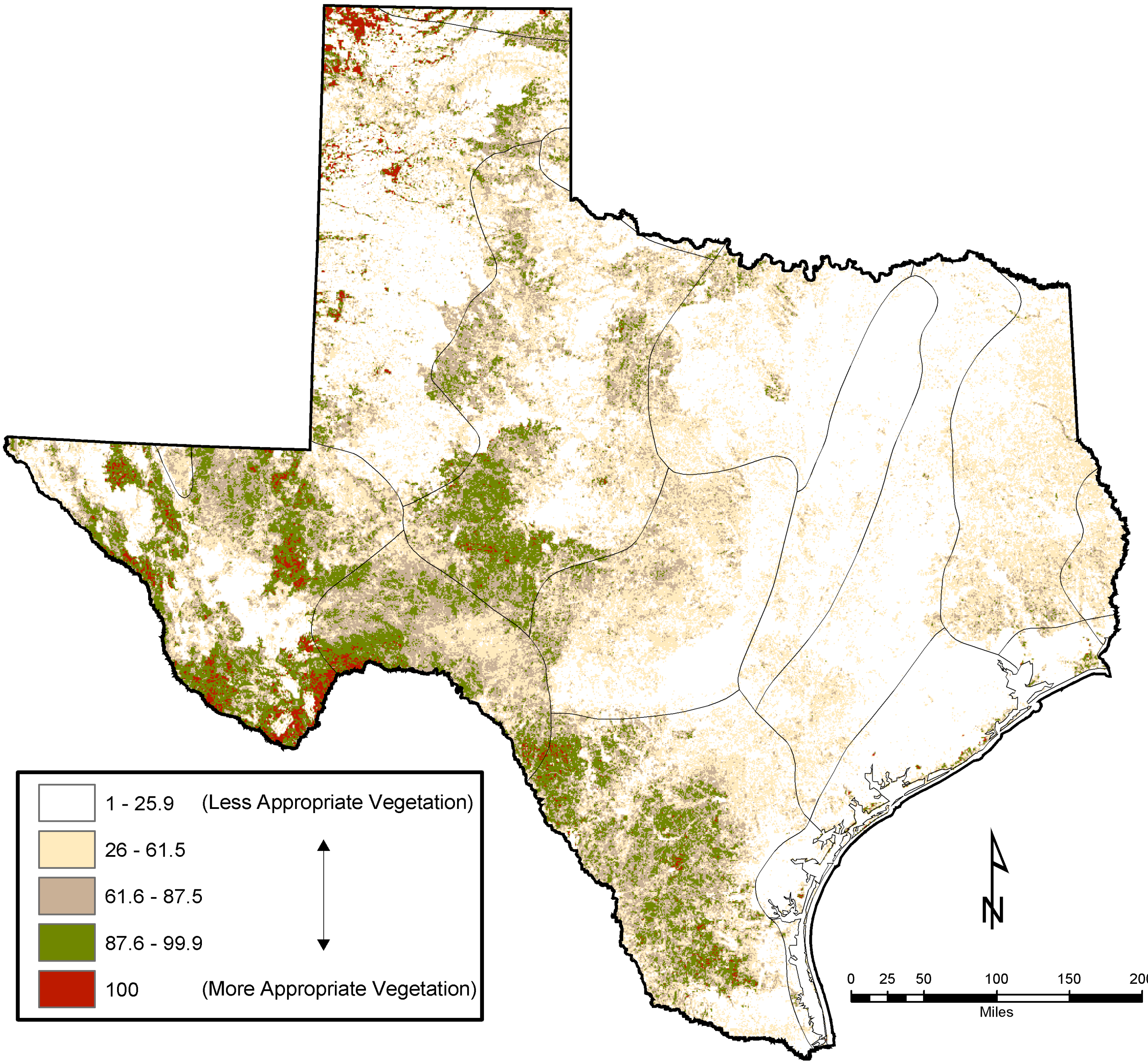

Figure B1. Map of diversity sub-layer: appropriateness of land cover. This map is used to produce the map of the diversity layer (Figure 5). Even though this map shows the entire state of Texas, the measures included in the diversity layer were calculated for each ecoregion.

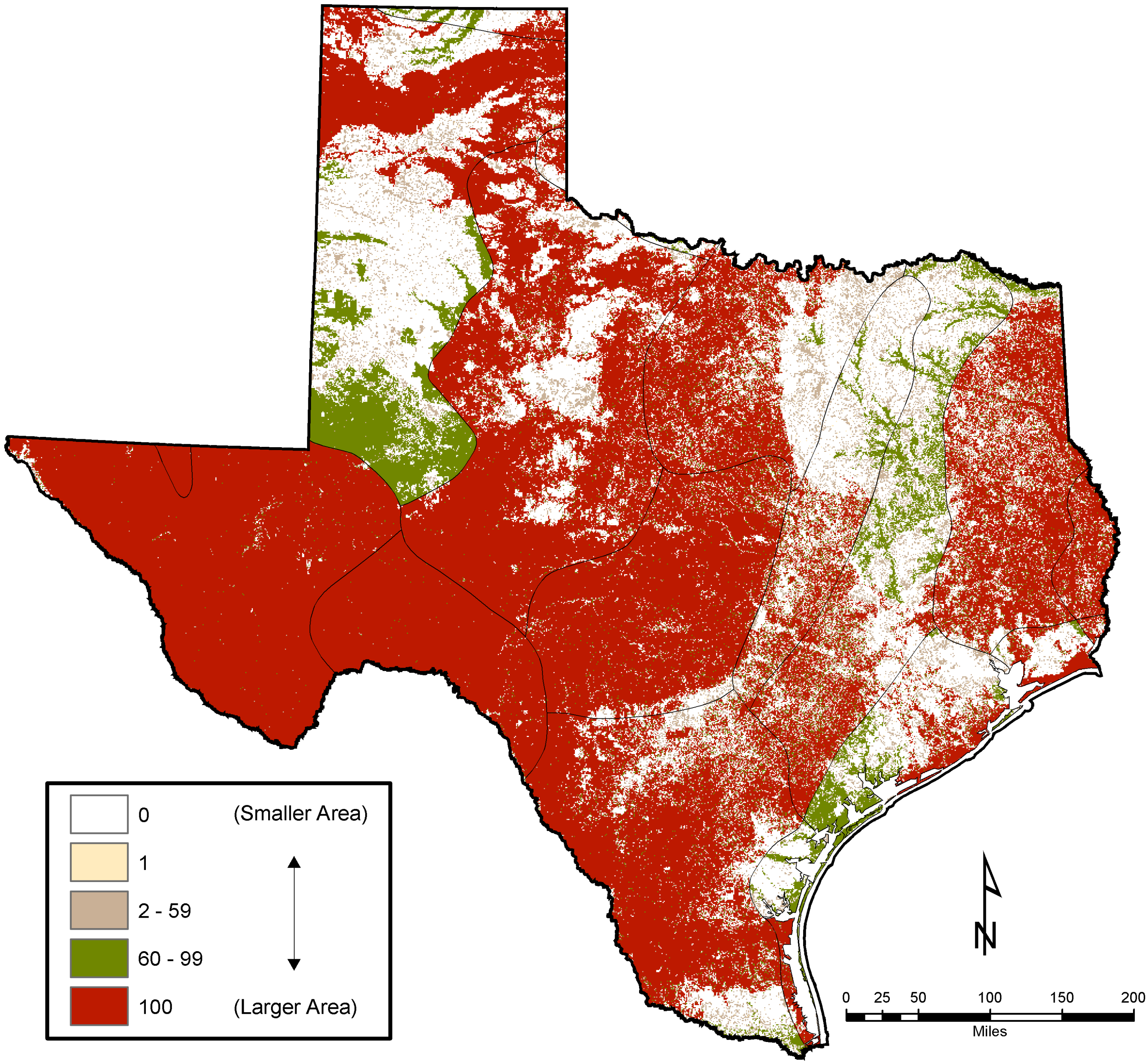

Figure B2. Map of diversity sub-layer: contiguous size of undeveloped land. This map is used to produce the map of the diversity layer (Figure 5). Even though this map shows the entire state of Texas, the measures included in the diversity layer were calculated for each ecoregion.

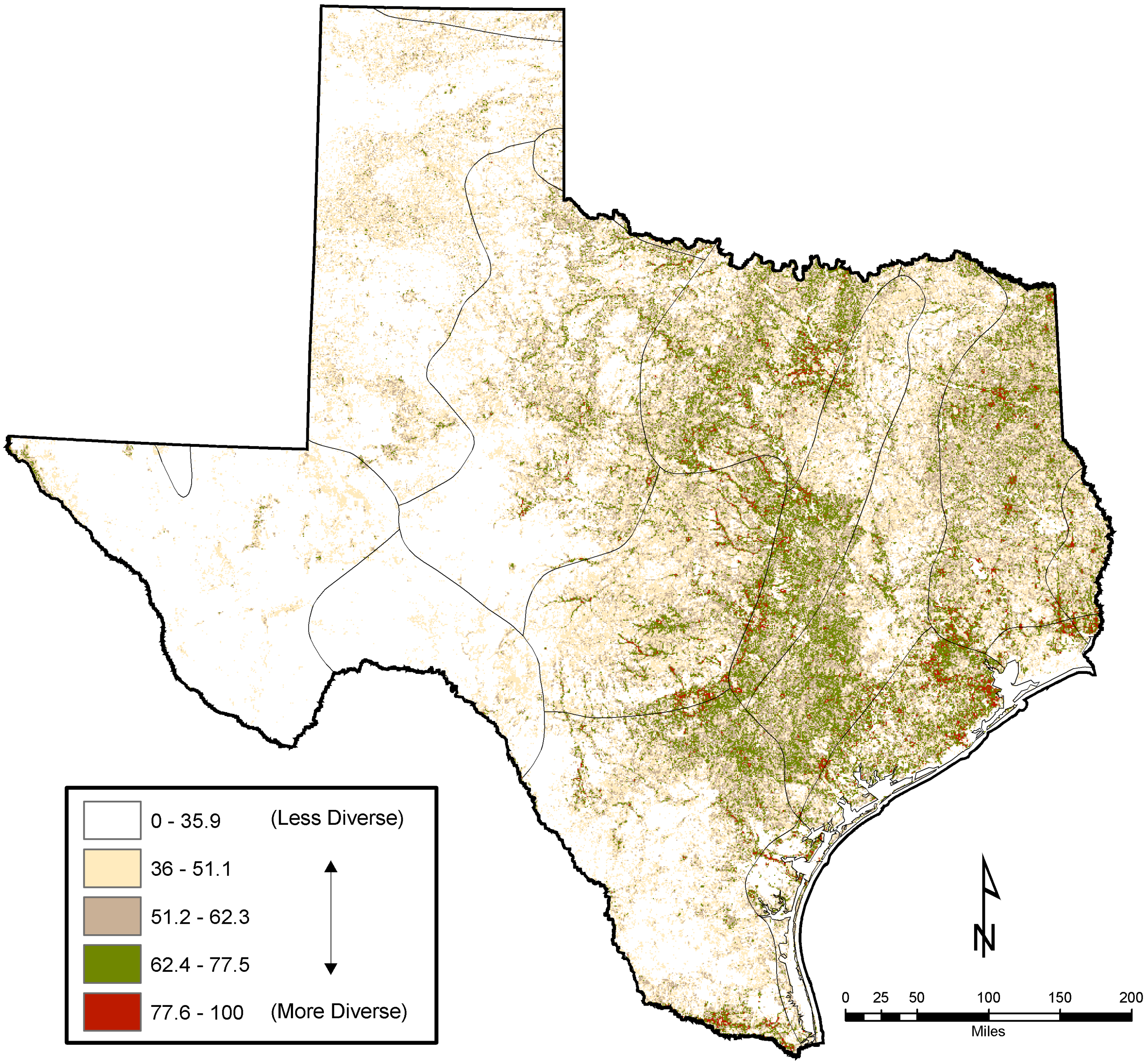

Figure B3. Map of diversity sub-layer: Shannon land cover diversity index. This map is used to produce the map of the diversity layer (Figure 5). Even though this map shows the entire state of Texas, the measures included in the diversity layer were calculated for each ecoregion.

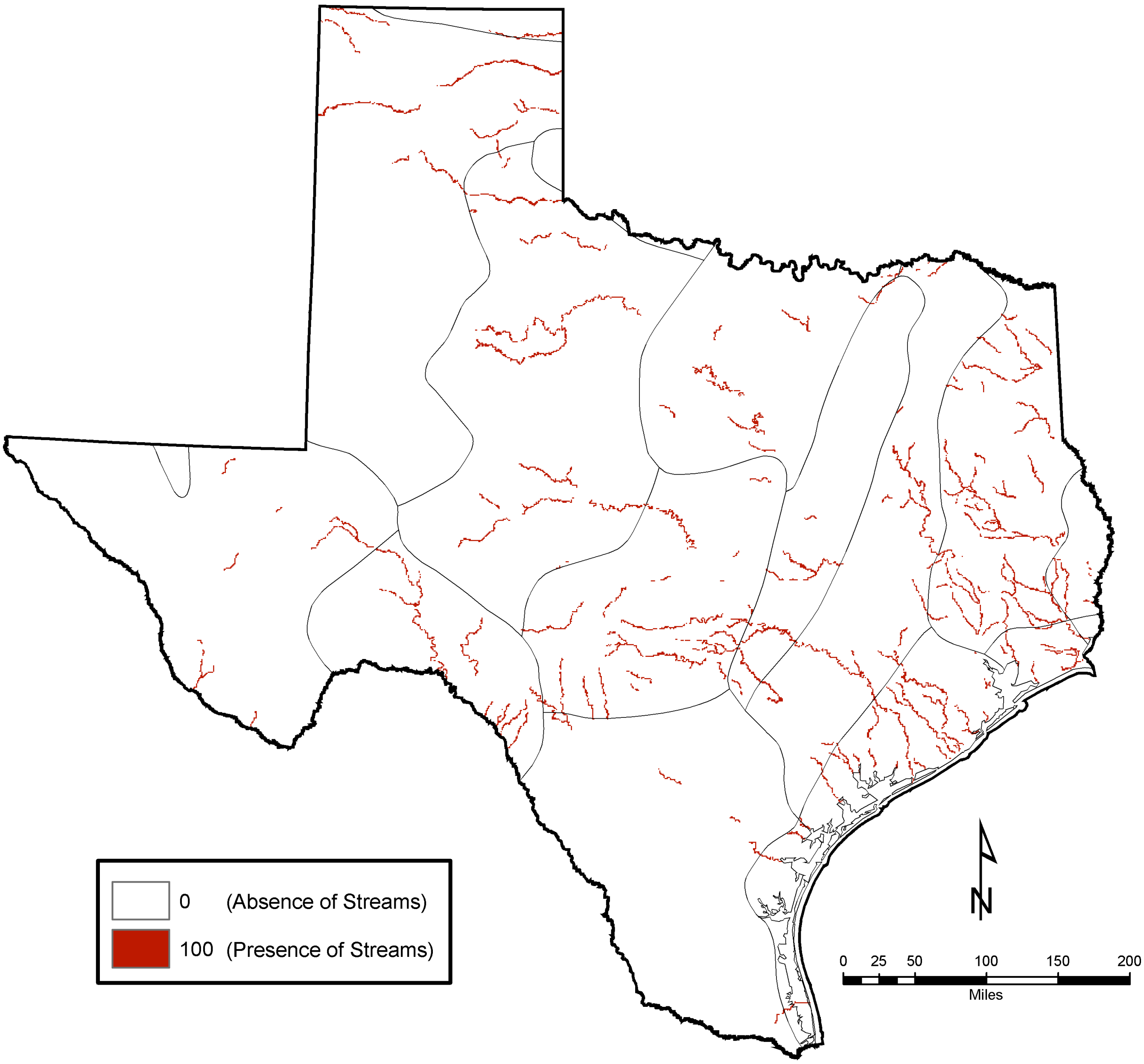

Figure B4. Map of diversity sub-layer: ecologically significant stream segments. This map is used to produce the map of the diversity layer (Figure 5). Even though this map shows the entire state of Texas, the measures included in the diversity layer were calculated for each ecoregion.

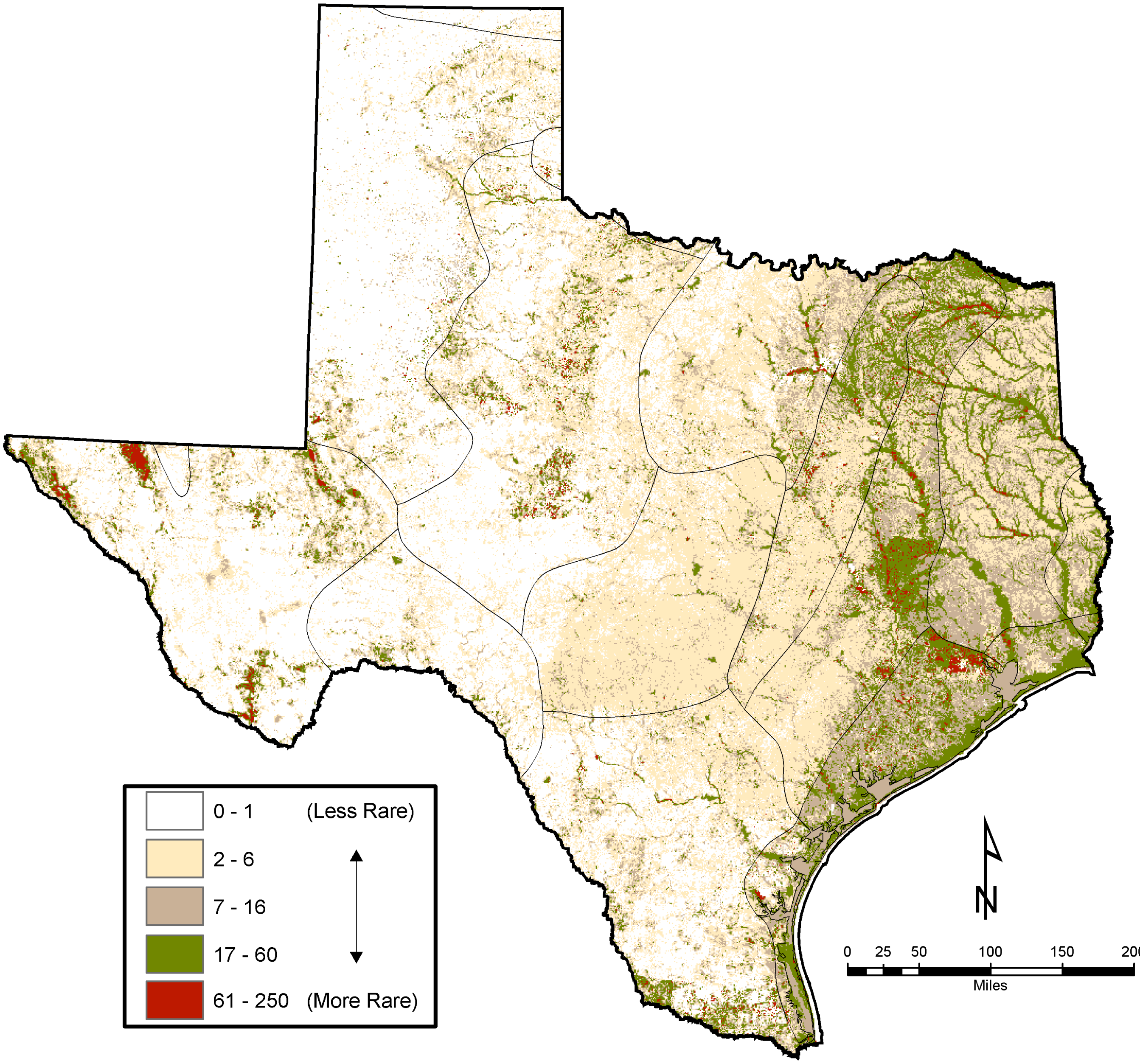

Figure B5. Map of rarity sub-layer: vegetation rarity. This map is used to produce the map of the rarity layer (Figure 6). Even though this map shows the entire state of Texas, the measures included in the rarity layer were calculated for each ecoregion.

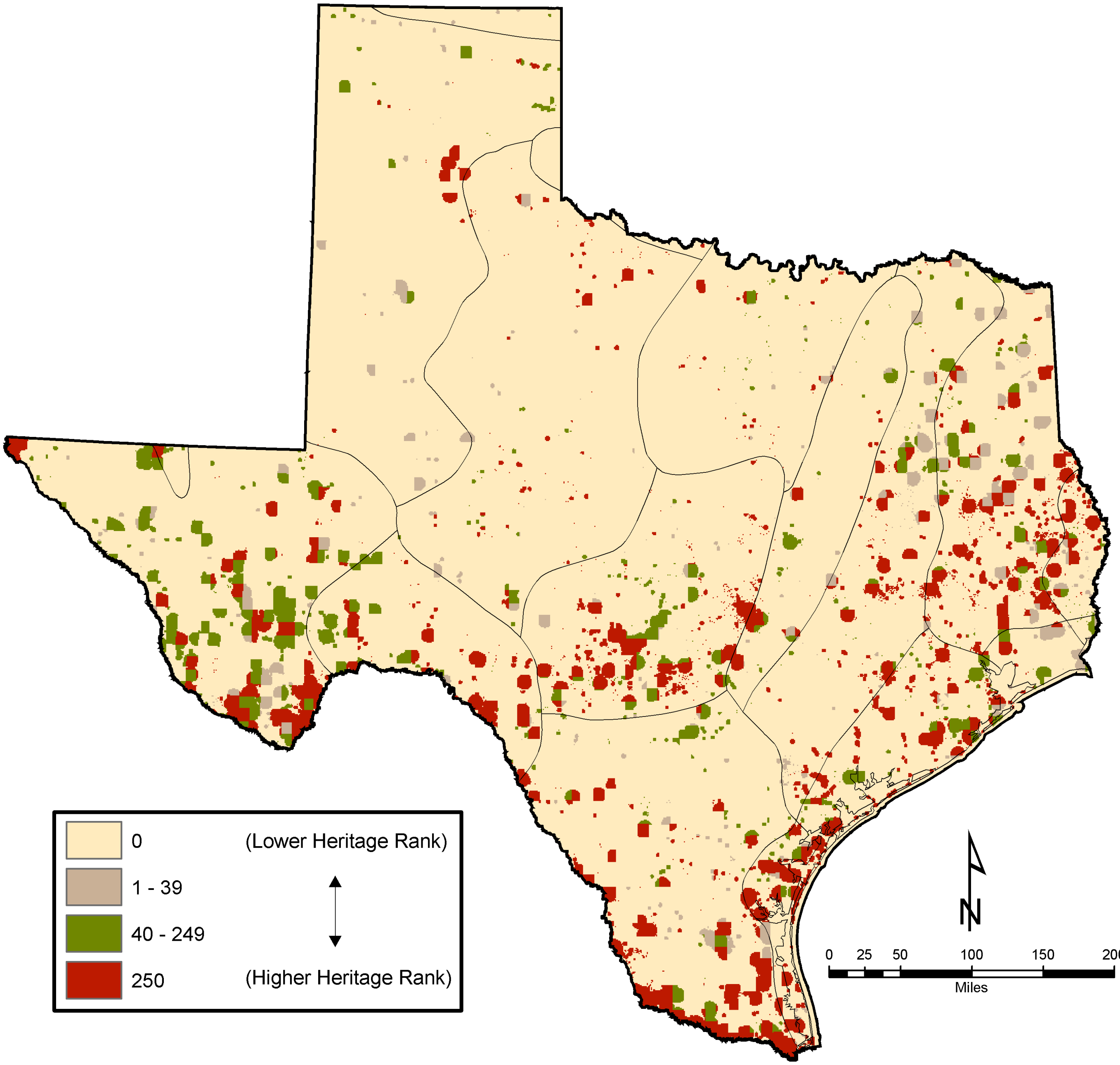

Figure B6. Map of rarity sub-layer: natural heritage rank. This map is used to produce the map of the rarity layer (Figure 6). Even though this map shows the entire state of Texas, the measures included in the rarity layer were calculated for each ecoregion.

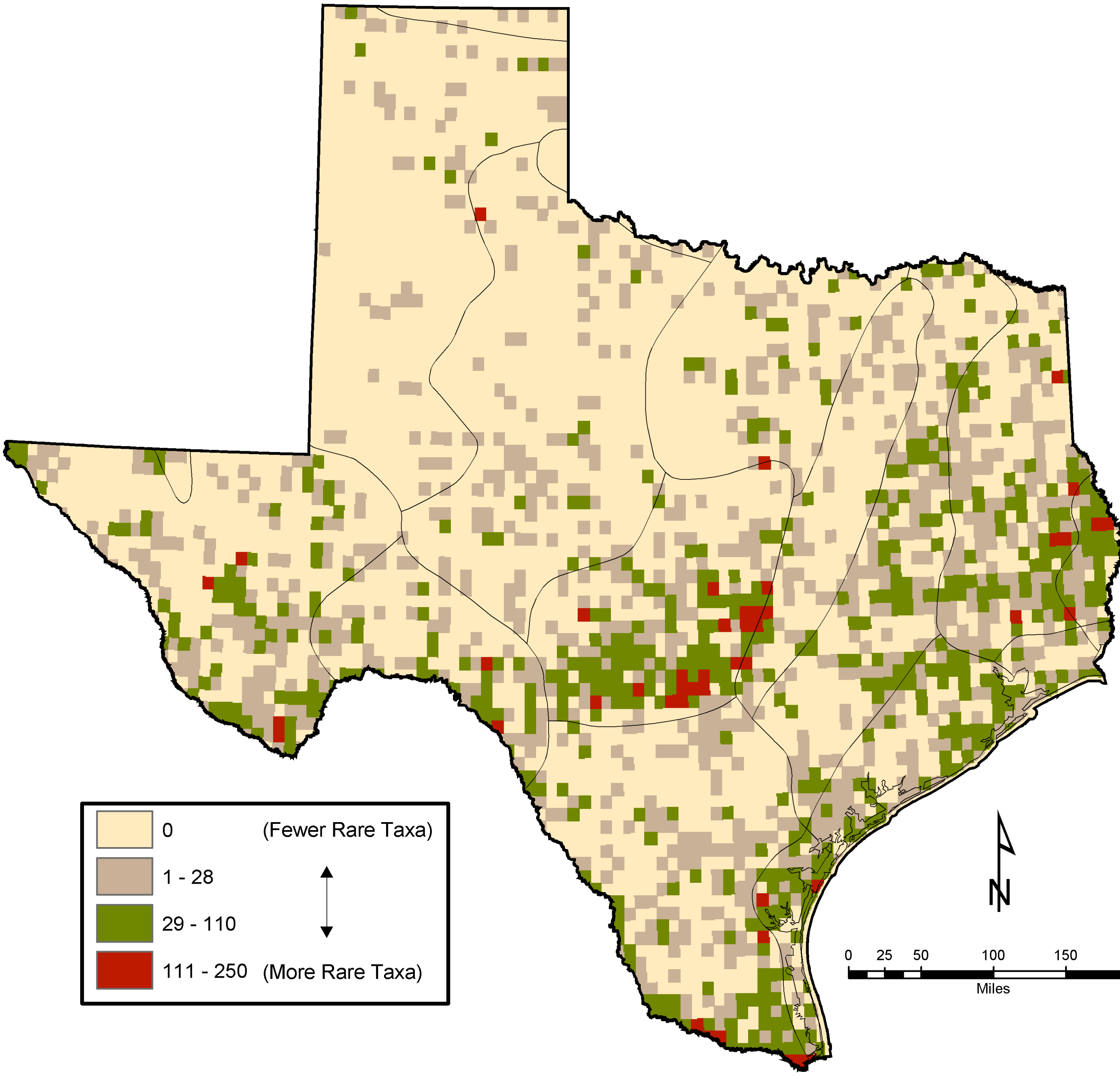

Figure B7. Map of rarity sub-layer: taxonomic richness. This map is used to produce the map of the rarity layer (Figure 6). Even though this map shows the entire state of Texas, the measures included in the rarity layer were calculated for each ecoregion.

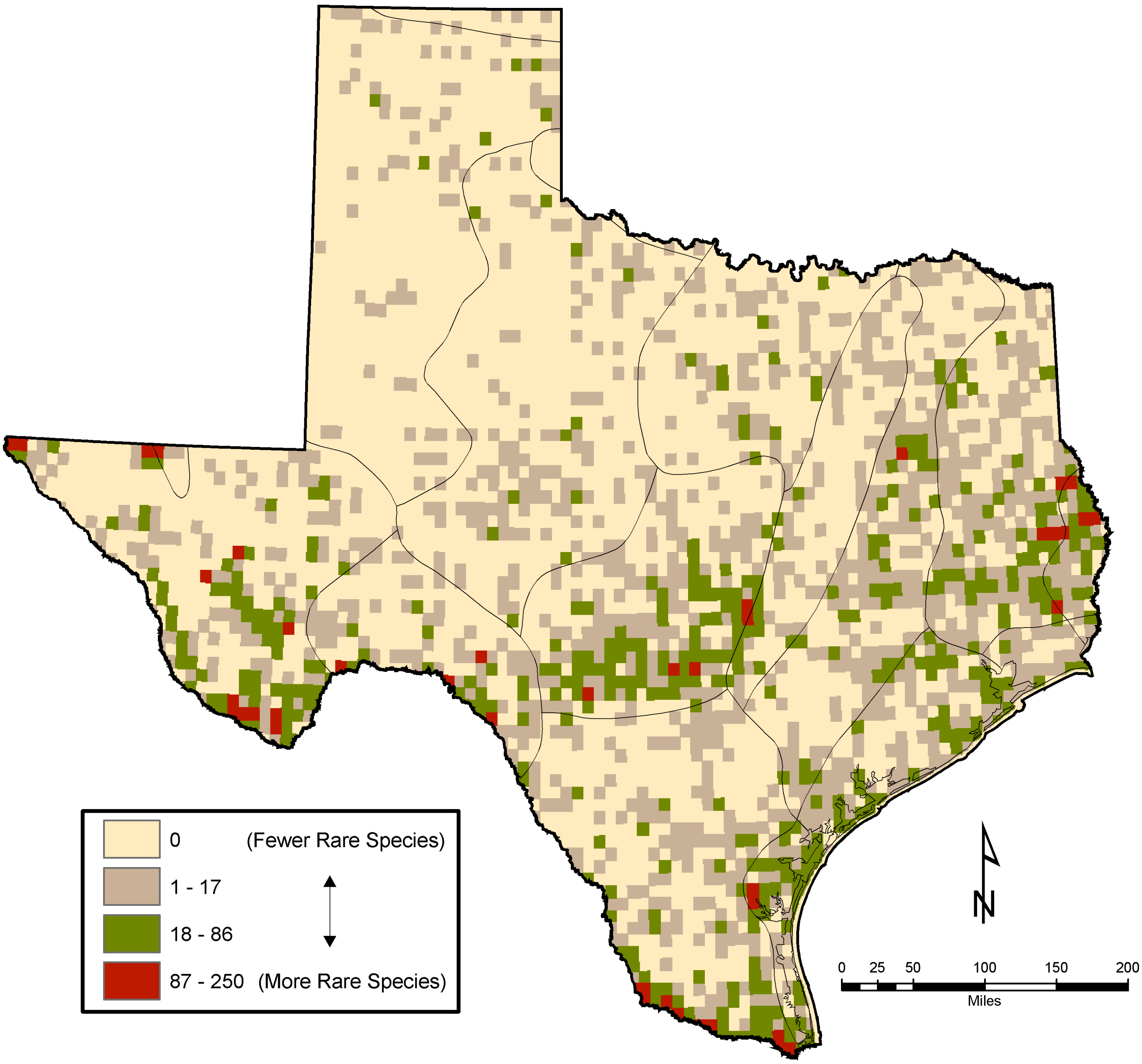

Figure B8. Map of rarity sub-layer: rare species richness. This map is used to produce the map of the rarity layer (Figure 6). Even though this map shows the entire state of Texas, the measures included in the rarity layer were calculated for each ecoregion.

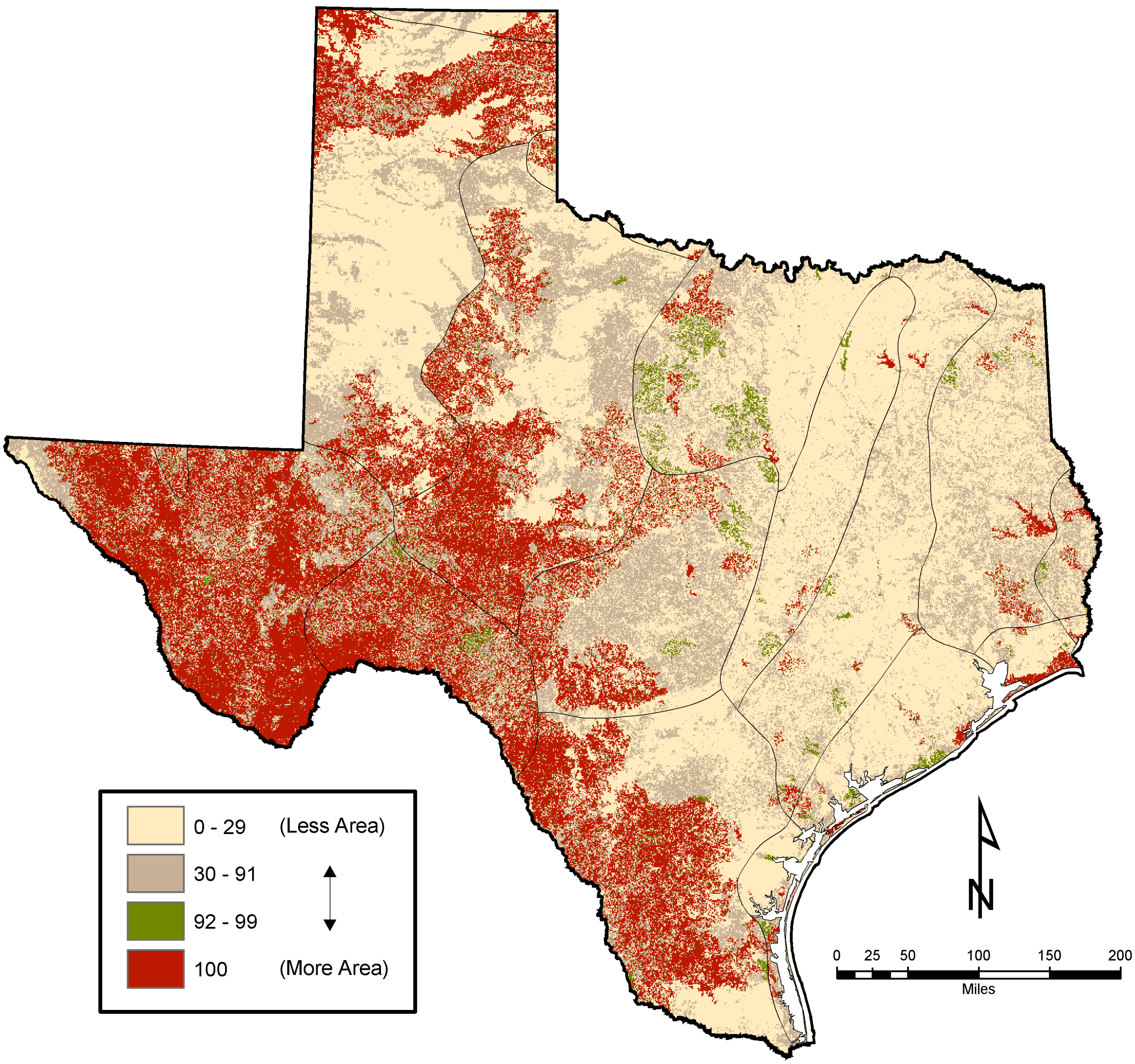

Figure B9. Map of sustainability sub-layer: contiguous land cover type. This map is used to produce the map of the sustainability layer (Figure 7). Even though this map shows the entire state of Texas, the measures included in the sustainability layer were calculated for each ecoregion.

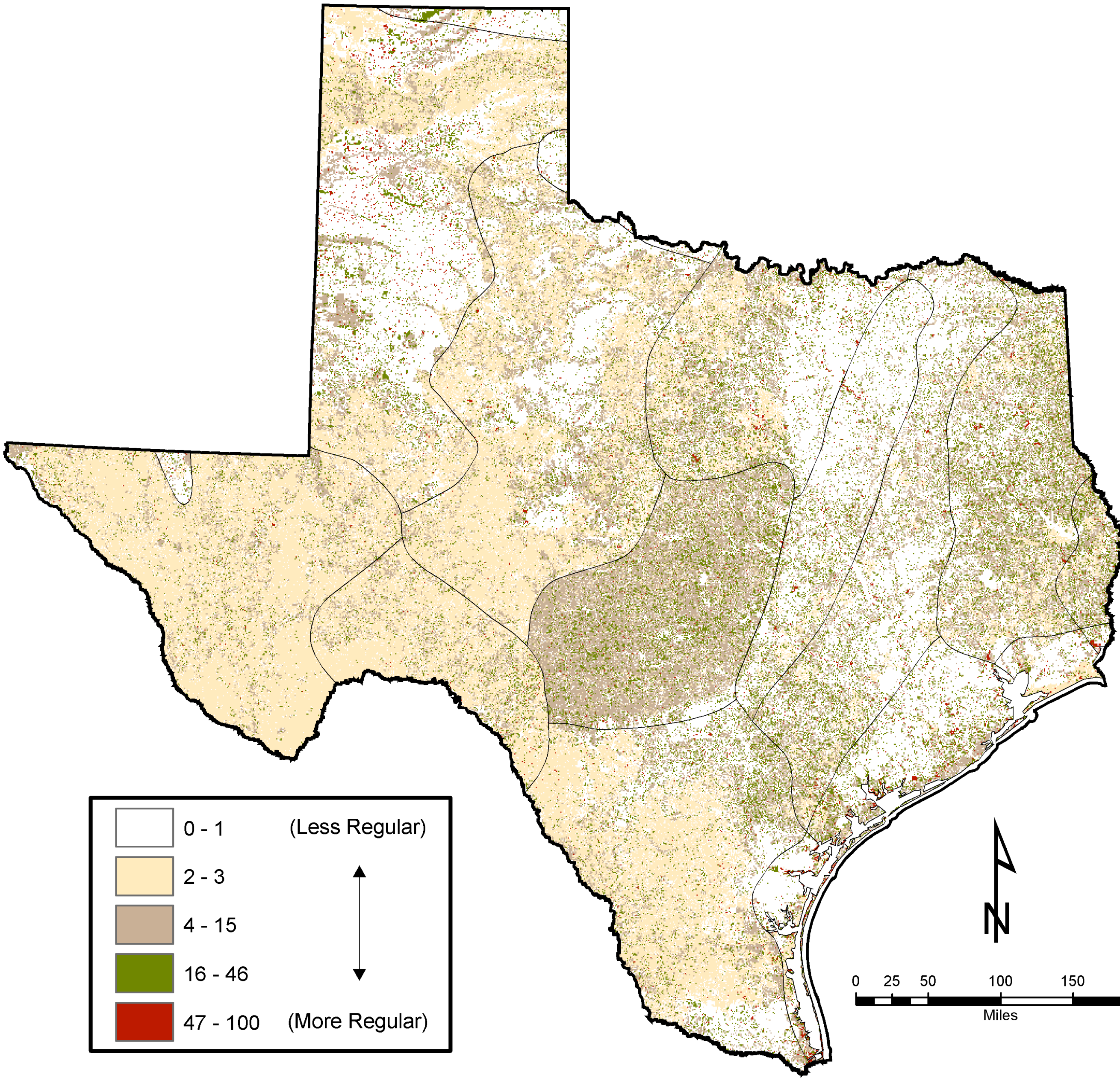

Figure B10. Map of sustainability sub-layer: regularity of ecosystem boundary. This map is used to produce the map of the sustainability layer (Figure 7). Even though this map shows the entire state of Texas, the measures included in the sustainability layer were calculated for each ecoregion.

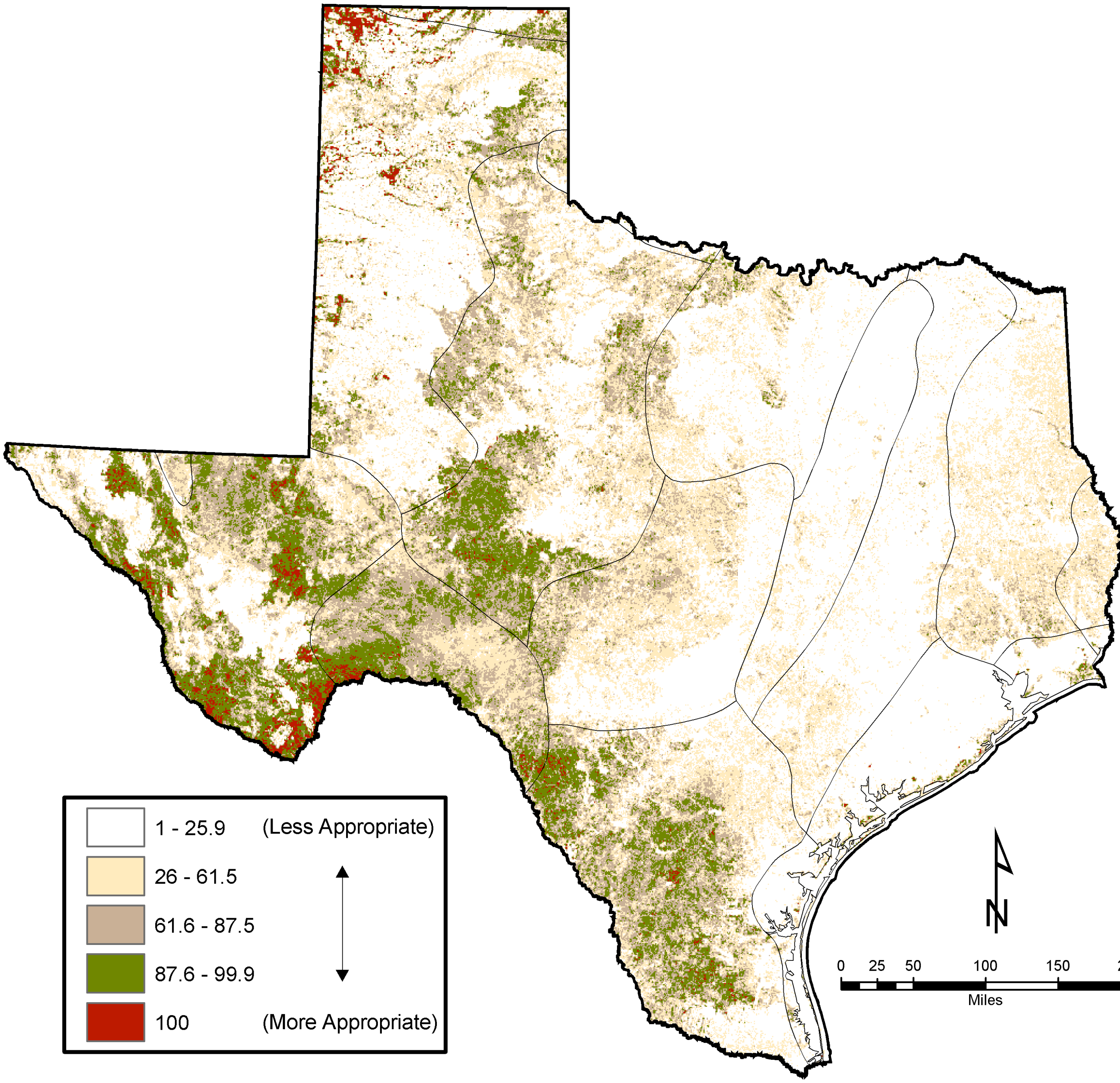

Figure B11. Map of sustainability sub-layer: appropriateness of land cover. This map is used to produce the map of the sustainability layer (Figure 7). Even though this map shows the entire state of Texas, the measures included in the sustainability layer were calculated for each ecoregion.

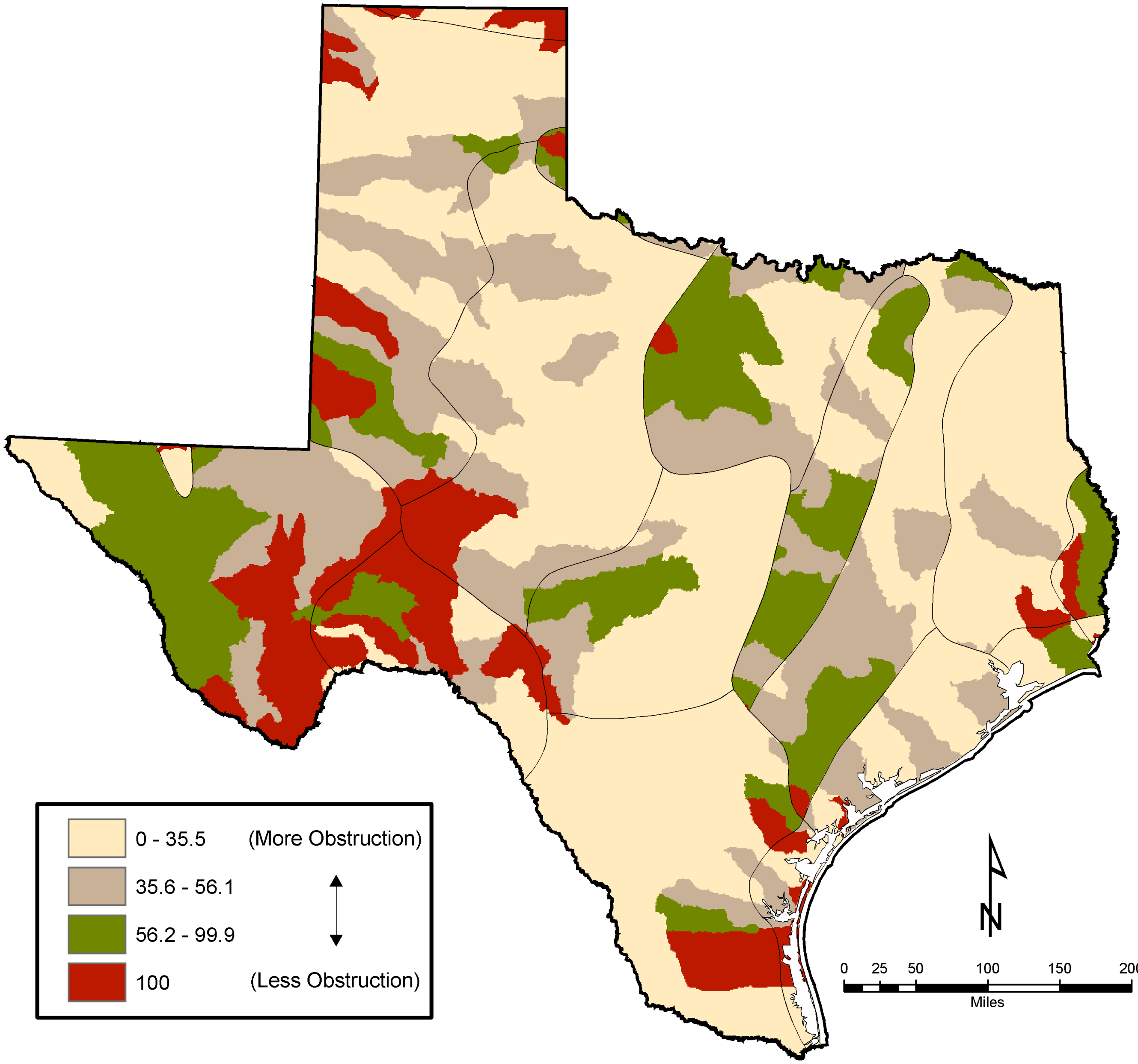

Figure B12. Map of sustainability sub-layer: waterway obstruction. This map is used to produce the map of the sustainability layer (Figure 7). Even though this map shows the entire state of Texas, the measures included in the sustainability layer were calculated for each ecoregion.

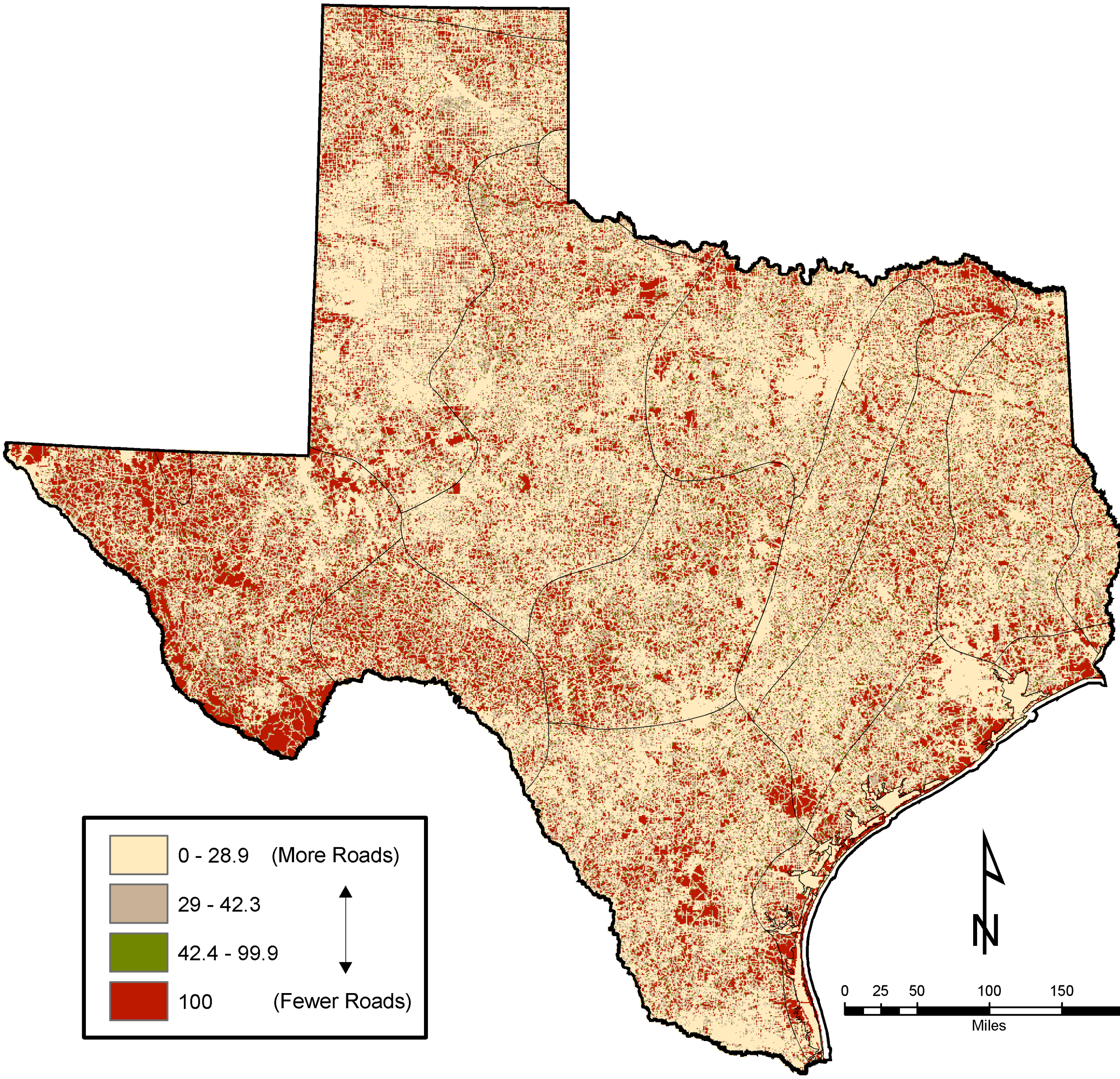

Figure B13. Map of sustainability sub-layer: road density. This map is used to produce the map of the sustainability layer (Figure 7). Even though this map shows the entire state of Texas, the measures included in the sustainability layer were calculated for each ecoregion.

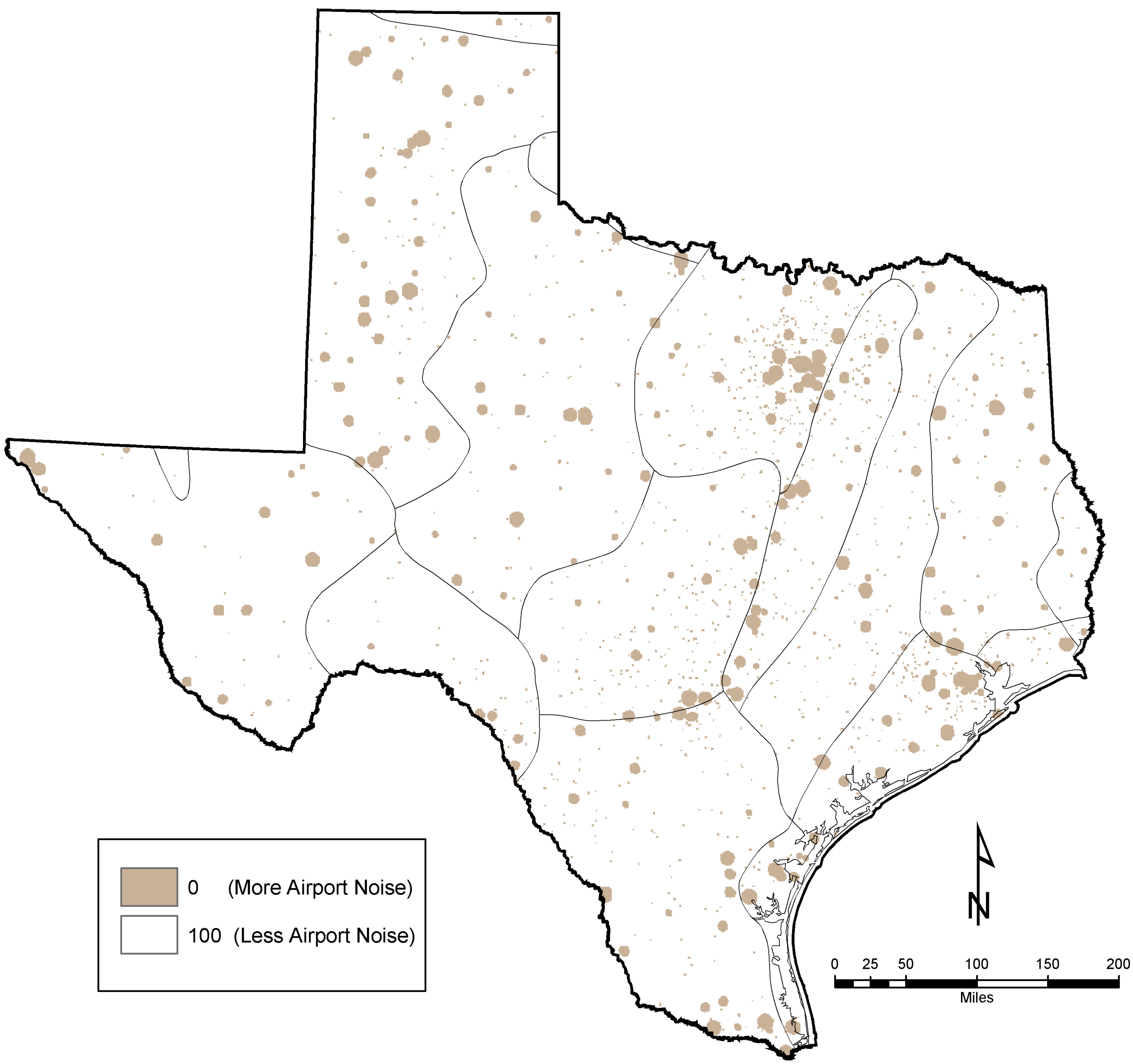

Figure B14. Map of sustainability sub-layer: airport noise. This map is used to produce the map of the sustainability layer (Figure 7). Even though this map shows the entire state of Texas, the measures included in the sustainability layer were calculated for each ecoregion.

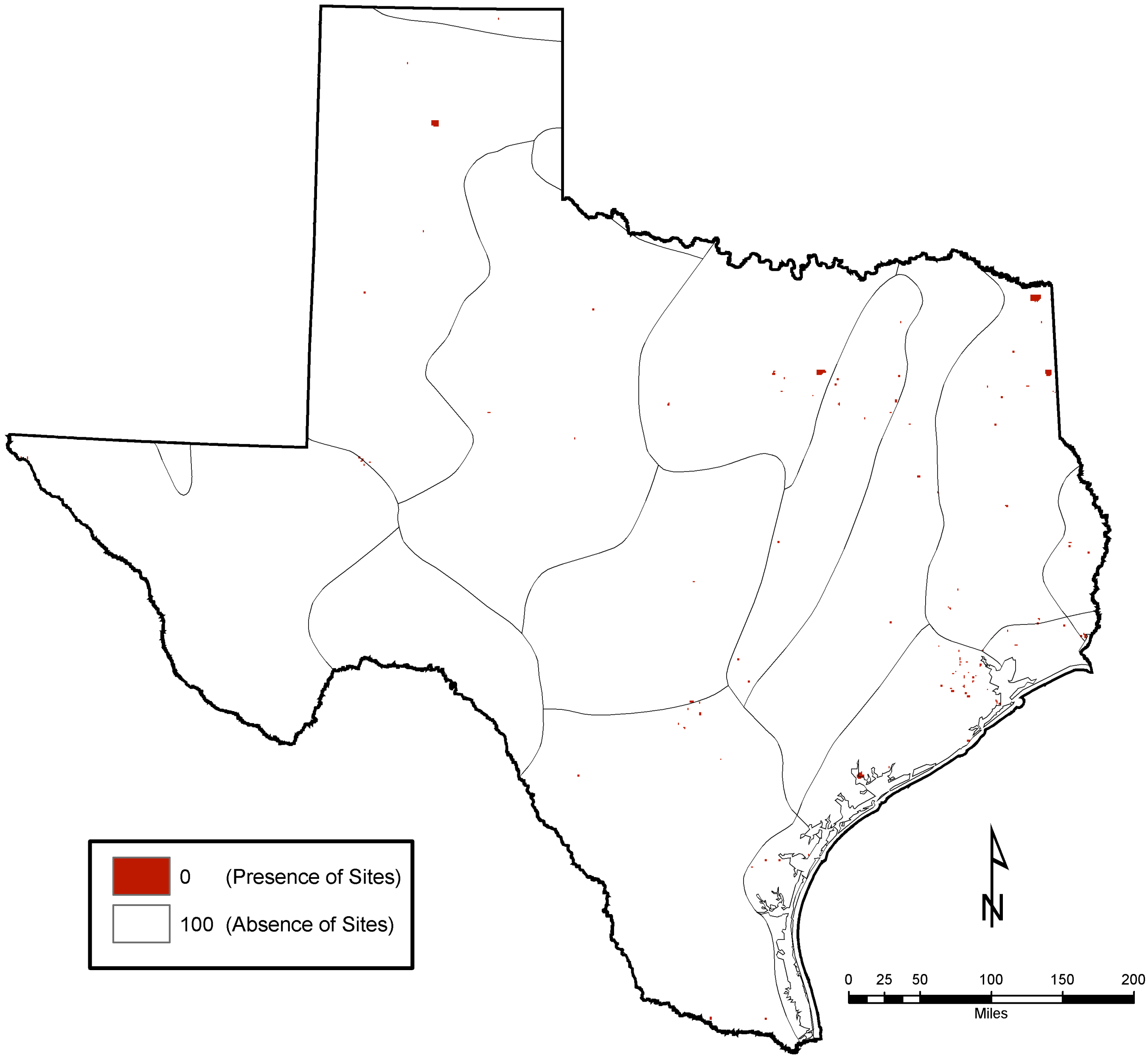

Figure B15. Map of sustainability sub-layer: Superfund NPL and state Superfund sites. This map is used to produce the map of the sustainability layer (Figure 7). Even though this map shows the entire state of Texas, the measures included in the sustainability layer were calculated for each ecoregion.

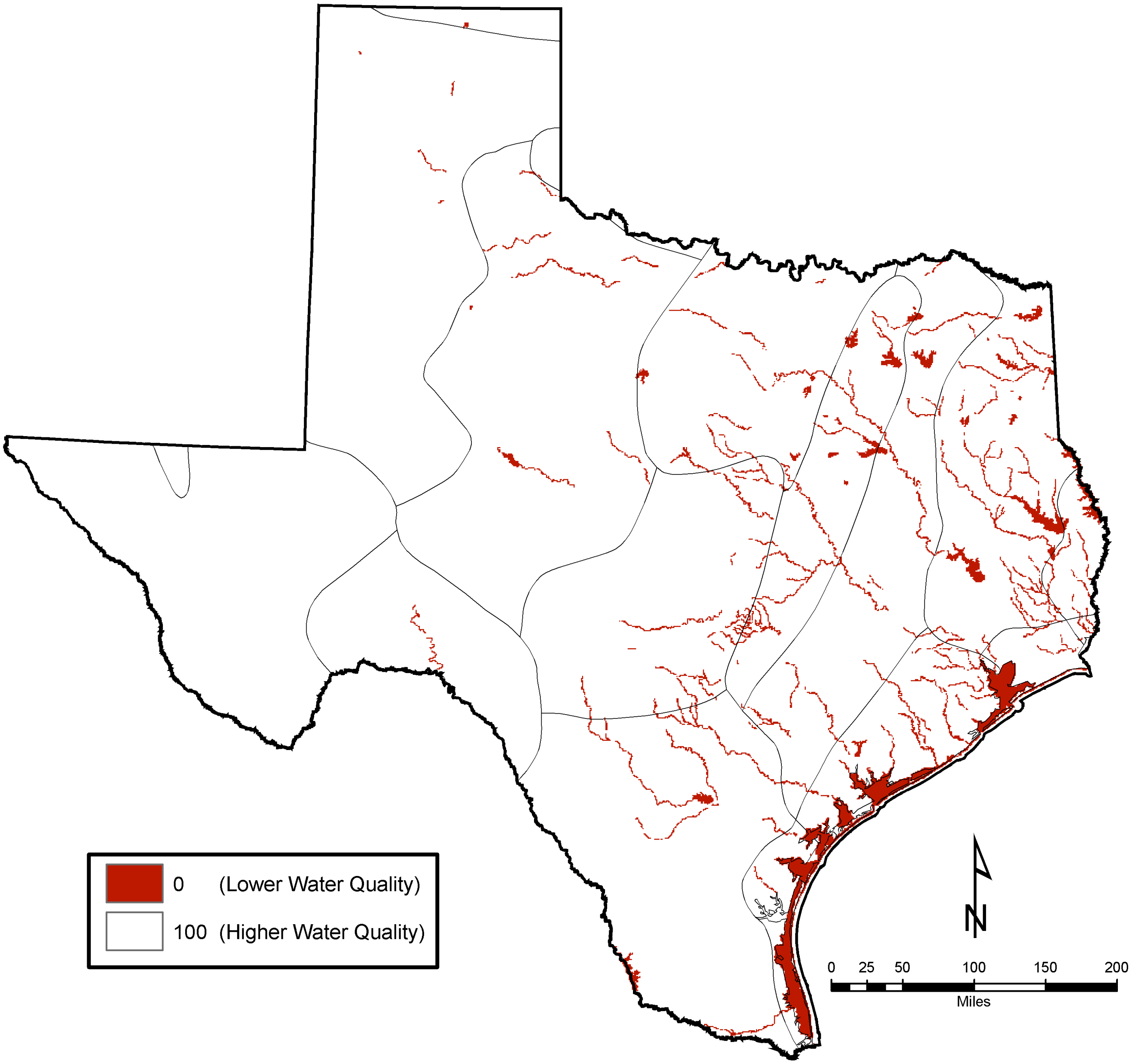

Figure B16. Map of sustainability sub-layer: water quality. This map is used to produce the map of the sustainability layer (Figure 7). Even though this map shows the entire state of Texas, the measures included in the sustainability layer were calculated for each ecoregion.

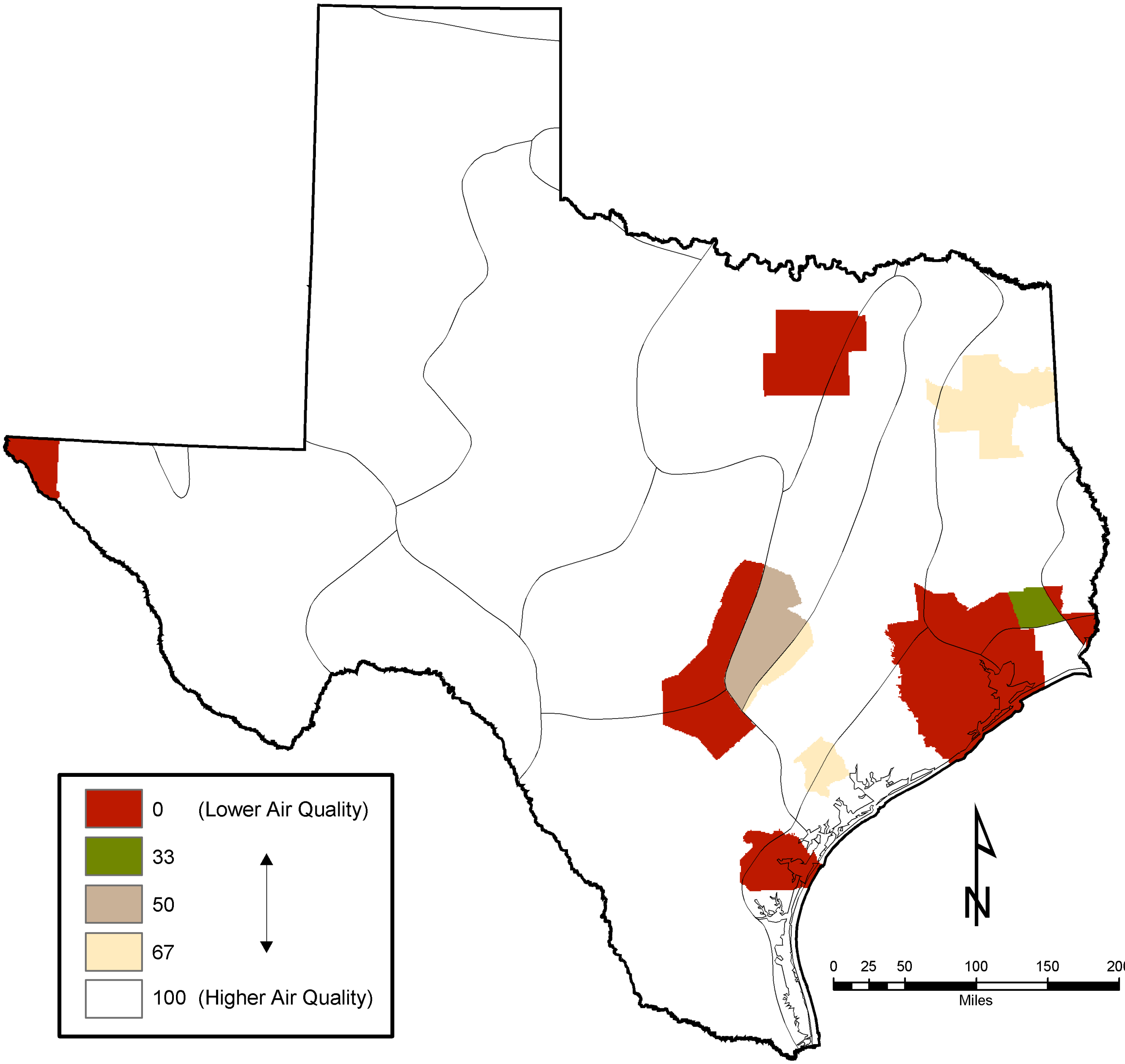

Figure B17. Map of sustainability sub-layer: air quality. This map is used to produce the map of the sustainability layer (Figure 7). Even though this map shows the entire state of Texas, the measures included in the sustainability layer were calculated for each ecoregion.

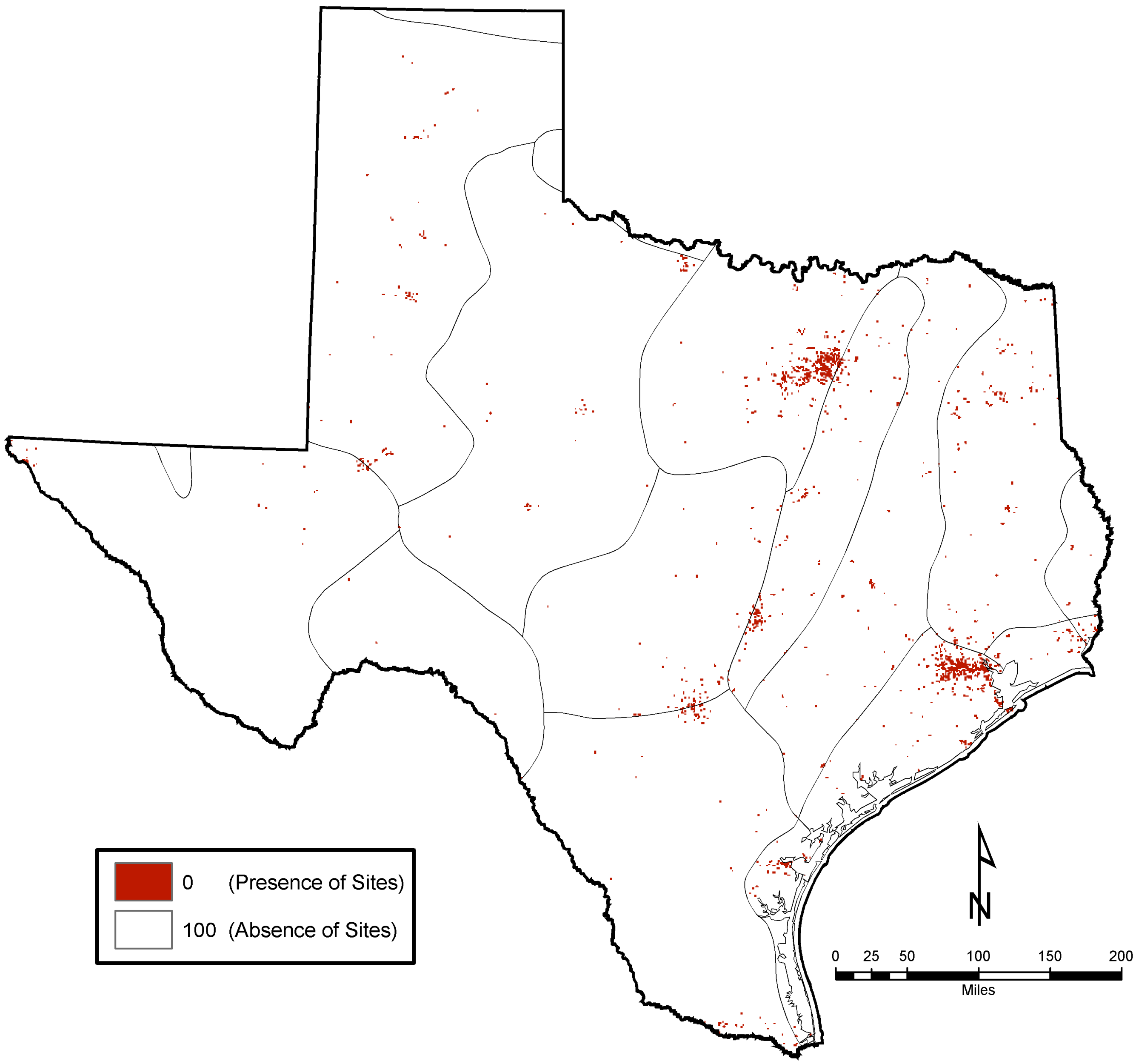

Figure B18. Map of sustainability sub-layer: RCRA TSD, corrective action and state VCP sites. This map is used to produce the map of the sustainability layer (Figure 7). Even though this map shows the entire state of Texas, the measures included in the sustainability layer were calculated for each ecoregion.

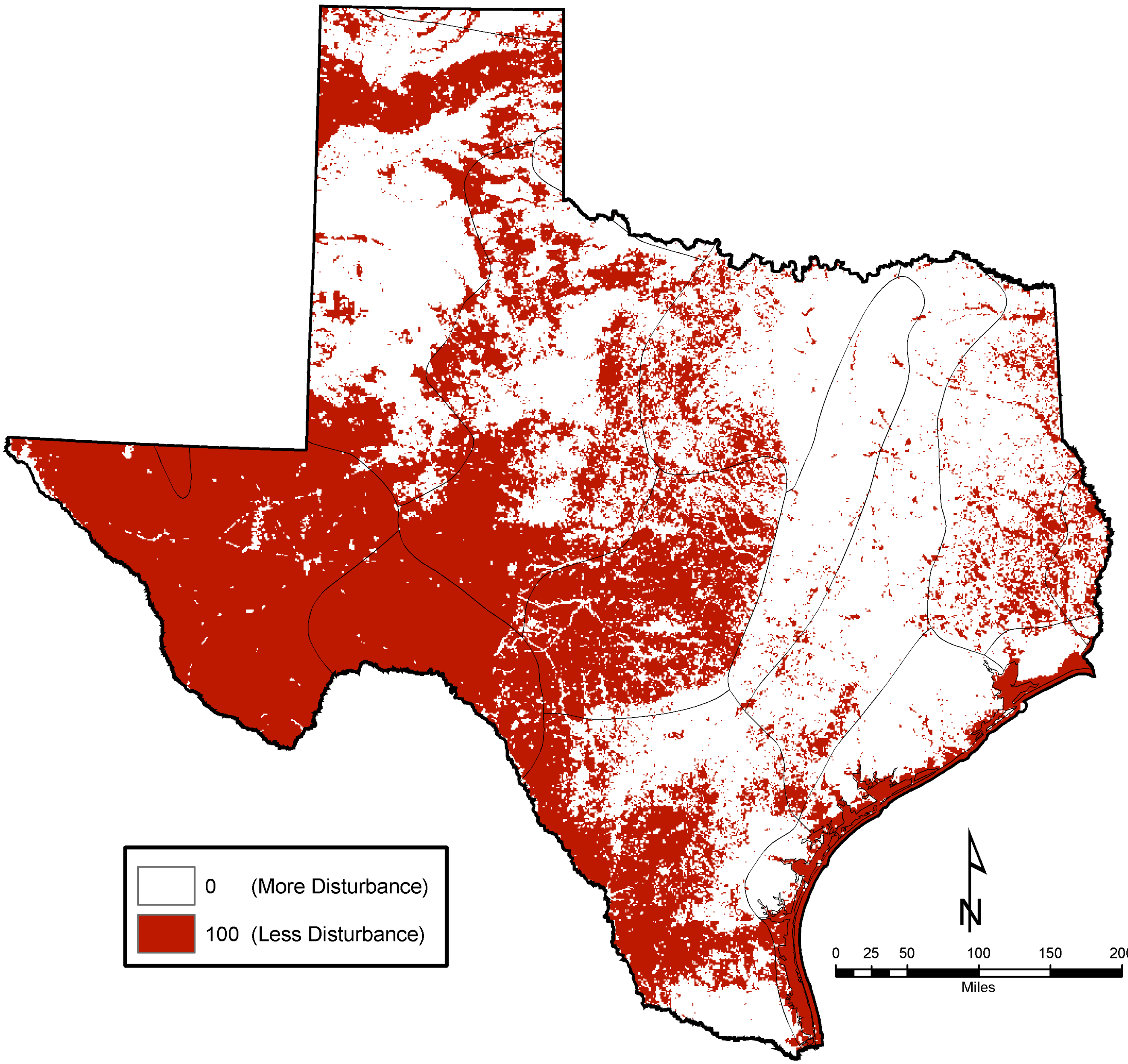

Figure B19. Map of sustainability sub-layer: urban/agriculture disturbance. This map is used to produce the map of the sustainability layer (Figure 7). Even though this map shows the entire state of Texas, the measures included in the sustainability layer were calculated for each ecoregion.

APPENDIX C
List of Acronyms

List of Acronyms

ATtILA	Analytical Tools Interface for Landscape Assessments
BCD, TXBCD	TPWD Biological Conservation Database
C	Carbon
C°	Celsius
Ca	Calcium
CD	Compact Disc
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
CO_2	Carbon Dioxide
CrEAM	Critical Ecosystems Assessment Model
Cu	Copper
CWA	Clean Water Act
DEM	Digital Elevation Model
DO	Dissolved oxygen
EO	Executive Order
EPA	U.S. Environmental Protection Agency
ESRI	Environmental Systems Research Institute
F	Farenheit

FAA	Federal Aviation Administration
Fed	Federal
FHWA	Federal Highway Administration
ft	Feet
FWS	U.S. Fish and Wildlife Service
GIS	Geographical Information System
GLO	General Land Office
G, GRANK	Global natural heritage rank, TEAP variable
ha	Hectare
Hg	Mercury
HUC	Hydrologic Unit Code
IH	Interstate Highway
K	Potassium
km^2, km	Square kilometer, kilometer
m^2, m	Square meter, meter
mm	Millimeter
MRLC	Multi-resolution Land Characterization
N	Nitrogen
NEPA	National Environmental Policy Act
NGO	Non-governmental Organization

NHD	National Hydrography Dataset
NLCD	National Land Cover Dataset
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPL	National Priority List (Superfund)
NRCS	Natural Resources Conservation Service
O	Oxygen
OAQPS	Office of Air Quality Panning and Standards
P	Phosphorus
PAH	Polycyclic Aromatic Hydrocarbon
PAR	Perimeter-to-Area Ratio
PNV	Potential Natural Vegetation
RCRA	Resource Conservation and Recovery Act
RCRIS	Resource Conservation and Recovery Information System
SAB	EPA Science Advisory Board
Se	Selenium
Si	Silicon
SLOSS	Single Large or Several Small
S, SRANK	State natural heritage rank, TEAP variable
STORET	EPA Storage and Retrieval System
T&E	Threatened and Endangered species

TCEQ	Texas Commission on Environmental Quality
TEAP	Texas Ecological Assessment Protocol
TERS	Texas Environmental Resource Stewards
THC	Texas Historical Commission
The Conservancy, TNC	The Nature Conservancy of Texas
TIGER	Topological Integrated Geographic Encoding and Referencing System
TMDL	Total Maximum Daily Load
TPWD	Texas Parks and Wildlife Department
TRI	Toxic Release Inventory
TSMS	Texas State Mapping System
TSD	Treatment-Storage-Disposal sites
TxCDC	Texas Conservation Data Center
TXDOT	Texas Department of Transportation
TWDB	Texas Water Development Board
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USDI	U.S. Department of the Interior
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
VCP	Voluntary Cleanup Program
Zn	Zinc

APPENDIX D
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